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CATASTROPHIST GEOLOGY

a magazine dedicated to the study of discontinuities in EARTH HISTORY

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of discontinuities in Earth history

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In evaluating an MS submitted for publication the following criteria are used, separately or together:

a) does it study discontinuities in Earth history?
b) does it clarify what catastrophist geology is about?
c) does it focus on subjects neglected or tabooed in the mainstream geological journals?

Cover: Photomicrograph of thin section of dunite (nicols //) from the Gardiner intrusion, E.Greenland. Dendritic magnetite within olivine (forsterite). From: Frisch W., Keusen H., 1977: Gardiner intrusion, an ultramafic complex at Kangerdlugssuaq, E.Greenland. Grønl.Geol.Unders.Bull.122, p.14. Scale: ⌊————————⌋ = 0.1 mm.

euphemistically speaking...

This journal is a low-budget venture (euphemistically speaking), so I have to do most of the dirty work myself: correcting, running to the setter, running to the photographer, correcting again, measuring, cutting, gluing, running to the printer, and then - so help me God! - correcting again. It is a miracle that the journal reaches you at all, so please don't become too impatient when it reaches you a couple of months late (euphemistically speaking).

Han Kloosterman

BONE BRECCIAS (COMMENTS on APOPHORETA-3)

Your comments on the Diceratherium remind me of similar deposits at the famous site of Pikermi in Greece. Of course, these are Upper Miocene and not of the period of immediate interest to you.

Augustus Sordinas
Dept. of Anthropology, Memphis State Univ.
Memphis, USA

The deposits of Pikermi certainly are of interest for the problem at hand. There are numerous deposits of comparable age in Europe: Cucuron, Mt.Luberon (France), Casino, Monte-Bamboli, Casteani, Monte Massi, Monte Cassini (Italy), and also in India (Siwalik) and California. Some of these yield large numbers of a few species of herbivores and would possibly fit the hypothesis of herds buried by landslides; others however yield many different species. I have found no comprehensive treatment of this subject.

Han Kloosterman

The quotation from the American Museum of Natural History implies that a pool, formed at an eddy in a river would have a quicksand bottom. There is only one way such quicksand could form, and that is by upward movement of groundwater through the bottom of the pool (see reference on Ink Pots springs). While this is not uncommon, there is no evidence (e.g. sorting of the sandy matrix of the bone breccia) presented for this.

Again referring to my Ink Pots paper it is clear that density differences between quicksand and "trapped" animals do present a problem. The animals may have died from exhaustion, but they would not have been "sucked in". Lacking further evidence for the quicksand hypothesis, I think the mud flow (liquefied sediment slide) solution is more likely.

The only way to solve this question is to collect all the evidence, including grain size distribution throughout the deposit, and detailed description of all "foreign matter" in the sediment.

Robert O.van Everdingen
Hydrology Research Div., Environment Canada
Calgary, Canada

Ref.: Van Everdingen R.O., 1969: The Ink Pots - a group of karst springs in the Rocky Mountains near Banff, Alberta. Can.J.Earth Sci. 6/4: 545-554.

The problem here is that an equally strong and pervasive uniformitarian influence exists in sedimentology as in palaeontology, with in the interpretation of sediments an aversion from even such common and minor catastrophes as rapid mass movements. Even if we are willing to consider catastrophist hypotheses, some basic data may be lacking, and thus the "cooperation" of the two specialities may lead to a typical case of "cross sterilisation", so common between two different disciplines or even branches of the same discipline.

Han Kloosterman

The hypothesis you object to also bothers me. The hall displaying the block of bones is to be revised and that will give us the opportunity to revise the captions for the exhibits. I think the critical evidence here is the extent of disarticulation of the remains which implies dismemberment of the carcasses and transport in a fluid and I see nothing improbable in the ordinary hydraulic agencies in a fluviatile regime. The concentration of remains can also be attributed to irregularities on the floor of the channel (observed during excavation) and the development of local eddies over the larger bones first deposited that trap further remains being swept downstream. The catastrophic factor may be the cause of death of a large group of animals and there are ways to assess this (unfortunately not tried with reference to the deposits in question), but normal stream transportation and deposition seems to me to be sufficient to explain the resulting deposit.

Richard H.Tedford
The American Museum of Natural History
Dept. of Vertebrate Paleontology
New York, USA

If we first of all keep separate the two possibilities: death and deposition by the same or by different causes, the disarticulation of the remains certainly suggests that death has occurred previous to deposition, but the high bone-to-sediment ratio of the layer and the paucity of species suggests rapid burial after death, pointing to a connection between the causes of death and burial. Museum specimens will provide no answer to these problems and we will have to go back to the field, and also compare the characteristics of many different bone layers. Are layers when consisting of only a few species always composed of herbivores? Are their sedimentological characteristics different from other bone layers? Doesn't there exist any classification of bone layers, or have I just been unable to find it?

Han Kloosterman

fossil cemeteries

From: V.A. Obruchev, 1959: Fundamentals of geology. Moscow. P. 321-326.

The history of life on the Earth really shows that during certain periods of time some genera, families, orders and classes of animals and plants came into being, attained their greatest development and distribution and then died out or considerably diminished. (...)

The leading part was played by climatic changes connected with the transgressions and regressions of the sea, the epochs of mountainbuilding and glacial phases. But in addition to these slow transformations of the fauna and flora connected with climatic changes, which can be regarded as catastrophes only with the aforementioned reservations, we find in the annals of the Earth proofs of real catastrophes which in a short time exterminated large numbers of animals and plants. Their remains form whole strata of the earth's crust and may be called fossil cemeteries or fields of corpses. (...)

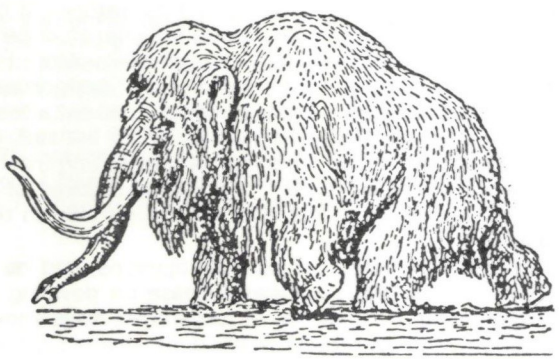
Cemeteries of reptile corpses of Cretaceous age are known in North America and East Africa. In Mongolia recent expeditions of the Palaeontological Institute of the U.S.S.R. Academy of Sciences have also discovered in various places accumulations of bones of Cretaceous pangolins and even their nests with eggs, and in other places accumulations of remains of Tertiary mammals. Similar cemeteries of Permian reptiles and amphibians are known in South America and in Germany. Accumulations of remains of Tertiary mammals are also found in the U.S.S.R. – Bessarabia, the Taman Peninsula and in Western Siberia near Lake Chelkar-Tengiz, in the basin of the Turgai River and near Pavlodar on the Irtysh River. Such cemeteries were recently discovered in the lower layers of the Tertiary conglomerates and sands in the lower reaches of the Chu River, in the Ketmen Ridge near Tashkent, and in the sands of the Kyzyl-Kum. Here the bones of the Cretaceous pangolins,

the scutes of turtles and the trunks of trees are badly chipped, rounded and mixed with pebbles representing remains of a vast cemetery of animals and plants of the end of the Cretaceous period which existed in this area and were eroded probably by torrents in the beginning of the Tertiary period.

The cemetery of Permian and Triassic herbivorous and carnivorous amphibians and reptiles discovered by Professor Amalitsky on the Northern Dvina has been known for a long time; the skeletons of these animals have formed a whole gallery, part of which is now on exhibition at the Palaeontological Museum of the Academy of Sciences in Moscow. This cemetery runs from the Unzha River across the Northern Dvina almost to the Kama River and the bones are found in a bed of sandstone with pebbles and sand from 20 centimetres to three metres thick, above and beneath which are mixed marls entirely devoid of remains. (...)

An even greater cemetery, but of the Tertiary period, was discovered in Carnegie Hill and University Hill in the State of Nebraska. Scores of thousands of skeletons of Rhinoceratidae – Diceras, Moropus and Dinoceras, are buried here in a layer only 15-65 centimeters thick. A slab cut out of this layer and measuring 1.65X2m. contains 22 skulls of Diceras and an enormous mass of its bones in a chaotic mixture. According to available figures 164,000 bones belonging to 820 skeletons of rhinoceroses have already been extracted, most of these bones from skeletons of Diceras. Numerous skeletons of a small antelope-like camel were found in two layers of a neighbouring hill. All the bones are very well preserved and exhibit no marks of teeth of predatory animals or rodents. This shows that the corpses did not stay on the surface very long and were buried very soon. So extensive an accumulation of remains of herbivorous animals of few species in one place can be explained only by a catastrophe which rapidly destroyed whole herds of them. (...)

The Bolshoi Lyakhov Island, the southernmost of the Novosibirskiye Islands, is essentially a cemetery of mammoths. Mammoth tusks and sometimes whole corpses of mammoths and other mammals were buried in great numbers in the Quaternary sediments; they have been preserved by the permafrost of the soil. In the coastal slopes washed by the surf the tusks thaw out in summer and fall on to the beech; in the past they were annually gathered in by traders who came from the continent. These abundant remains of large animals on a relatively small island which was unable to provide food for them is accounted for by the fact that as late as the beginning of the Quaternary period the land of Siberia reached much farther north and at the end of the last glacial epoch was broken up, large areas sinking into the sea. The herds of mammoths living on this land sought safety on the areas which remained intact. The Bolshoi Lyakhov Island was one of the asylums where the animals accumulated in large numbers. But it had already been separated from the continent by a wide strait and so became a cemetery for the animals who rapidly starved to death. This was a real catastrophe.



USGS VERSUS FRINGE

JOHAN B. KLOOSTERMAN

Rio de Janeiro

Some Fortean events are less damned than others, and some come so close to acceptance that they even transgress the boundary between fringe and mainstream, either to stay there or to cross back again, sometimes repeatedly. Some of these stubborn unusual events remain damned for only a few decades, while others stay on the Index of scientific priesthood for hundreds of years.

From the orthodox universitary viewpoint only the damnations of the past are of importance. The case of meteorites for instance is quoted again and again. Their existence had been known for thousands of years (in Mediterranean Antiquity iron was 'the heavenly metal'; compare the words *siderurgy* and *sideral*), but they were at the end of the 18th century suddenly condemned, then readmitted. However, the ever-ongoing interplay of rejection and acceptance between the mainstream and fringe is usually kept out of the scientific records. I wonder whether any science historian studies the vicissitudes of the events or the realms of knowledge that are censored out of our official journals? T. Kuhn (1962) advocated against a prevailing mainstream view of steady progress in science, a somewhat catastrophist view of progress-by-jumps. He sees revolutions as brought about, however, through the *internal* contradictions generated by the scientific endeavour, and takes no account of the interaction between mainstream and fringe. He only discusses minor changes of "paradigm" – for instance the discovery of oxygen –, no macro-jumps such as the switch from alchemy to chemistry, whereas we legitimately may wonder whether there is anything in our understanding of the world which makes the discovery of oxygen probable and in the meantime renders alchemy ununderstandable.

The history of the US Geological Survey provides some interesting examples of the fringe-mainstream interaction. Early in this century the USGS was charged with the responsibility of giving advice on mineral resources, including water supplies. Large numbers of enquiries arrived about dowsing, and a project was set up to provide an official answer. A paper was issued (Ellis, 1917), describing dowsing and its history ("a curious superstition") and listing some 500 references ("an enormous volume of uncanny literature"). Many curious facts are related, some of them quite thought-provoking. For instance, the rules sometimes prescribed for the cutting of the dowsing twig "partook largely of heathen sorcery and astrology"; in 1659 the divining rod was denounced by a Jesuit as an instrument of the devil, and in 1701 a decree against it was issued by the Holy Inquisition. And so – when the paper's verdict is that "water witching" is useless and that "further tests by the USGS would be a misuse of public funds", the representatives of official Science emerge once more as direct successors of the established Churches in the repression of ancient lore and knowledge.

In summary, the USGS paper was based on personal opinions, and no tests had been made. Fifty years later however (24.IX.67) a News Release on dowsing was published, stating that "Controlled experiments by a variety of researchers have shown conclusively that water witching (dowsing) is not a reliable method of locating ground water". No

negative evidence had turned up since 1917, and positive evidence was ignored, such as the investigations of Tromp (1949, 1956), or the extensive research carried out in the USSR. The USGS was clearly bluffing when they converted mere opinions into "controlled experiments", and when interpellated, they had to recant. William T. Pecora, who had been director since 1965, admitted in 1969, in a letter to R.C. Willey, secretary of the American Society of Dowsers, that the USGS did not have enough information to speak negatively on the value of dowsing. Pecora started to refer all queries about dowsing to the American Society of Dowsers (see Willey, 1970).

Earthquake lights, luminous phenomena reportedly seen shortly before, during and shortly after earthquakes, have been relegated for some time (perhaps a century) to the limbo of damned facts, but they are now being readmitted, though halfheartedly, in another News Release of the USGS, ten years after the Water Witching Bull. Somebody up there clearly has "seen the light" and successfully pressed for a News Release, which was published after proper caution had been taken in the wording. Positive statements are placed between quotation marks ("the existence of earthquake lights is well established, John Derr said"), and the final remark that a theory of earthquake lights could possibly be useful for earthquake prediction is made to sound as if it were an apology for the News Release. I also wonder whether anybody in the USGS office was thinking of the past 50 years of research by Forteans (see for instance Fort, 1941; Corliss, 1974; and articles in half a dozen Fortean magazines) when they wrote "earthquake lights are worthy of *additional* (my emphasis) scientific investigation, John Derr said". Or is "*additional* investigation" some esoteric USGS-English, like the "*further* tests" of dowsing, not meaning what it does to non-initiates?

Criticism of terms, however, without giving due credit, would surely by a sign of pettiness. After this year's Release, researchers will be able to refer to it and perhaps encounter less reviewer's resistance when trying to publish their results. They may even obtain funding for research. Hopefully the whole research community will be able to apply its brain power, laboratory facilities and communication network to the investigation of earthquake lights. Some kind of positive step has been taken, there is no doubt about that; here is a point scored for the fringe, and for science. *Gaudeamus igitur,* and let us congratulate the USGS for their courage.

To finish, a prediction. Also in the USGS more and more geologists realise that ignorant and superstitious are those people who accept on faith the untested opinions of others. Some years from now a News Release will be issued, stating that dowsing is worthy of *additional* scientific investigation. It will be followed by a new Water Supply Paper, with an extensive bibliography covering also the period since 1917, and recommending the use of public funds for *further* tests.

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(703) 860-7444 / Frank Forrester July 3, 1977

U. S. GEOLOGICAL SURVEY NEWS RELEASE

EARTHQUAKE LIGHTS

Earthquake lights — luminous phenomena that have been observed to occur at the time of some earthquakes — are worthy of additional scientific investigation, according to a U.S. Geological Survey, Department of the Interior, scientist.

John S. Derr, a geophysicist at the USGS Denver, Colo., field center, said there are difficulties in trying to explain these phenomena because very few scientists have worked on the question of earthquake lights. "The reason," he said, " is simply that most reports of these lights are the personal observations of untrained observers. Nevertheless, observations have been made for many years, and the existence of earthquake lights is well established."

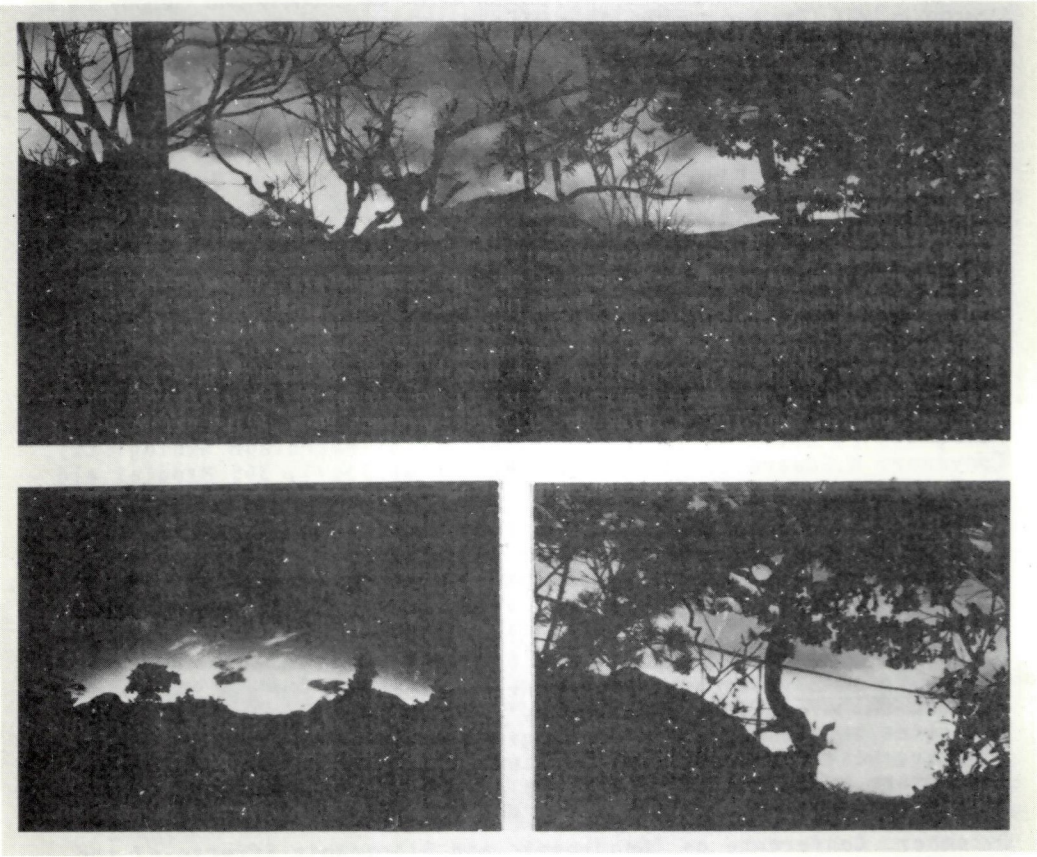
In a recent (May-June 1977) issue of the USGS Earthquake Information Bulletin, Derr noted that the first known investigations of earthquake lights were carried out in the early 1930's by two Japanese seismologists, Torahiko Terada and Kinkiti Musya; the latter collected some 1,500 reports of lights from the Idu Peninsula earthquake which occurred at 4:30 a.m., November 26, 1930. In most of the accounts of the lights from the Idu Peninsula quake, the sky was lit up as if by sheet lightning, with nearly all observers agreeing that the duration of a single flash was much longer than that of lightning. Others described the lights as resembling auroral streamers, beams and columns, fireballs, or as a ruddy glow in the sky, with distances of the lights estimated to be 50 miles to the east of the quake's epicenter, nearly 70 miles to the northeast, and more than 40 miles to the west. The lights were seen both before and for some time after the earthquake, but were most conspicuous during the middle of the shock.

There have been a few reports of earthquake lights observed at sea. In January 1922, for example, when an earthquake occurred off the coast of northern California, an observer noted a glow at sea which was first taken to be a ship on fire. In October 1926, a flash of light at sea which resembled a "transformer exploding" was observed at the time of an earthquake centered in Monterey Bay.

More recently, Yutaka Yasui, a professor of physics at Dokkyo Medical College, Japan, collected photographs of lights seen during the Matsushiro earthquake swarm in Japan from 1965 to 1967. At least 18 of the 35 sightings are not explained by meteors, twilight, zodiacal light, arcing power lines, or distant lightning.

Yasui has also commented on observations of lights during the October 1, 1969, earthquake at Santa Rosa, Calif., which were seen extensively over the Santa Rosa area and described in terms of lightning, electric sparks, Saint Elmo's Fire, fireballs, or meteors. Some people claimed to have heard sounds like esplosions. But just how many reports are genuine lights and how many are caused by the effects of the earthquake on manmade objects cannot be determined.

Dr. Cinna Lomnitz, a seismologist of the National University of Mexico, who recently visited the People's Republic of China, was told about some of the most spectacular sightings of earthquake lights on record. The lights were observed at the time of the great China earthquake of July 28, 1976. The reports are consistent with those of previous sightings, including seeing the sky light up like daylight in the epicentral area. The lights were also reported as far as 200 miles from the epicenter. They were mainly white and red, and bright enough to wake people up, thinking their room lights had been turned on.



Photographs of earthquake lights taken by T. Kuribayashi, a dentist, of Matsushiro, Japan, during the Matsushiro earthquake swarm which lasted from 1965 to 1967. Photos were taken at night.

Kuribayashi has taken the only known photographs of earthquake lights, some of which are reproduced in the article "Earthquake Lights," by John S. Derr, geophysicist, U.S. Geological Survey, in the May-June 1977 issue of the USGS Earthquake Information Bulletin. Earthquake lights – luminous phenomena that have been observed to occur at the time of some earthquakes – are worthy of additional scientific investigation, Derr says.

One theory that might explain the occurrence of earthquake lights involves violent low-level air oscillation, suggested, for example, by J. E. McDonald, formerly a physicist at the University of Arizona, Tucson. In the case of the Hebgen Lake earthquake in Montana in 1956, McDonald considered the possibility that space charge might be transported through a vertical distance of 300 meters (about 900 feet) by aerodynamic drag from a landslide triggered by the quake. McDonald said this could possibly set up temporary electrical imbalances that would lead to luminosity. McDonald added that the mechanism would not account for most of the sightings which do not include landslides, but might be one of several mechanisms capable of producing luminosity.

A second theory to explain the phenomena is linked to the "piezoelectric" effect in quartz-bearing rock, discussed in a paper by David Finkelstein, a physicist at the Yeshiva University, New York, and J.R. Powell, a physicist at the Brookhaven National Laboratory, New York, in a report before the International Union of Geodesy and Geophysics in Moscow in 1971. (The piezoelectric effect refers to the setting up of an electric potential in certain rocks – particularly quartz – as the result of stress changes.) Some evidence exists that the stress accumulated in rocks over a period of years may begin to be released very slowly several days before a large earthquake. This straining could lead to generation of a high seismoelectric potential, generated by stress on piezoelectric quartz in the rocks, and the resultant discharges might be seen several hours before the actual fault break of the major earthquake. If this theory is correct, it may be possible to develop electrical monitoring methods for earthquake prediction.

MEETINGS

1978

April 11. "Uniformitarianism - a contemporary perspective", symposium organised by the Society of Economic Paleontologists and Mineralogists (a division of the Amer. Assoc. of Petroleum Geologists). Convenor: H.Edward Clifton, USGS (Marine Geology), 345 Middlefield Road, Menlo Park CA 94025, USA.

May 10-13. "Sasquatch and Similar Phenomena", a conference on humanoid monsters organised by Prof.Dr. Michael Ames, Museum of Anthropology, University of British Columbia, Vancouver, B.C., Canada. The primary focus will be on the large, hairy, erect ape-like creature known as "Sasquatch" in Canada, "Bigfoot" in the USA, and as "Late Neanderthal Man" in the Soviet Union.

September 12-21. "Regional influences on the origin and course of development of geological theories", symposium organised by the Committee on the History of Geological Sciences and to be held in Münster, West Germany. An exhibition of geological and historical literature of recent years will be arranged. Convener: Prof.Dr. H.Hölder, Geol.-palaeontol. Inst. der Universität, Münster.

December. Conference on "Geodynamic and Biodynamic Effects of the Late Miocene (Messinian) Salinity Crisis in the Mediterranean. Rome, Italy.

1979.

December. Symposium on "Experimental Petrology of Extraterrestrial Materials and their Origin". Canberra, Australia.

NEOCATASTROPHISM? by Otto H. Schindewolf (1896-1971) is an address to the 113th General Assemblee of the German Geological Society held in September 1961 in Hamburg, and was published in 1963 in the journal of that Society (Deutsche Geologische Gesellschaft, Zeitschrift 114/2: 430-445).

Publication in English by permission of the Society (Hannover, West Germany). Translation by V. Axel Firsoff (Glastonbury, U.K.). Derek V. Ager of Swansea University College, U.K., has been so kind to check the palaeontological terms and names.

NEOCATASTROPHISM?

OTTO H. SCHINDEWOLF (1896-1971)

(Geological-palaeontological Institute,
Tübingen University, West Germany)

Abstract

The acceptance of faunal discontinuities in the history of the Earth has lately been, somewhat disparagingly, described as neocatastrophism and represented as a regression to the long-discredited ideas of Cuvier and his time. A re-examination of the issues has yielded the result that at the turning points of the great geological eras, and to a lesser extent at the boundaries of formations, there have occurred fundamental changes in the composition of the animal world, produced by the massive and more or less simultaneous extinction of numerous stocks and the appearance of new ones. This universal phenomenon must be regarded as a reality, and its causal interpretation requires postulating factors that are universally active. An admissible interpretation may be seen in the effects of influxes of high-energy cosmic radiation.

1. Introduction

D.L. Stepanov (1959a) has bestowed on me the somewhat doubtful honour of describing me as the "most important and consistent spokesman of the idea of neocatastrophism in contemporary palaeontology". By neocatastrophism in the sphere of palaeontology he understands the opinion expressed by me that in the geological evolution of organisms, and in the animal kingdom in particular, there have been turning points, or faunal discontinuities,

of profound importance that are characterized by a widespread, more or less simultaneous extinction of numerous stocks and an emergence of new ones or blossoming out of other stocks.

This conception is, of course, not new, nor does it come from me. In the final analysis it forms the basis, if perhaps not clearly expressed, of our long-established division of the history of the Earth into the Proterozoic, Palaeozoic, Mesozoic and Caenozoic. The originators of this classification obviously had a clear feeling that at the boundaries of each "zoically" determined era there were marked transformations of the animal world, where the sum of formations or systems would always add up to a category of a higher order.

Stepanov mentions the palaeontologists A.H. Müller, N.D. Newell and G.S. Simpson as further supporters of this point of view in the Western world. He rejects the interpretations proposed by them or us and believes that they contradict Darwin's teaching of gradual evolution, natural selection and extinction as a normal process. It is further noteworthy that such convinced Neodarwinians as Newell and Simpson are to be branded as Darwin renegades.

Obviously the recognition of episodes of radical transformation in the living world, which forces itself upon any observer, regardless of his political persuasion, is widespread among the Soviet Russian palaeontologists as well. Stepanov lists a few representatives; in reality, however, their number is much greater, and even the ionizing radiation, first mooted by myself in 1950 as the cause of these phenomena, has latterly been increasingly invoked by Russian investigators. Indeed, it appears to be a growing fundamental conviction precisely among the Soviet Russian stratigraphers that there exists a natural organization in the history of the Earth that has to be unravelled.

It is, therefore, singularly surprising that Stepanov denies the occurrence of turning points in the biological evolution which form the signposts in any natural system of division. He does, on the other hand, recognize quite clearly in a general description of the Carboniferous System (1959b) that the rejuvenation of the organic world constitutes an important criterion for separating the systems and their sub-divisions. The individual geological divisions would thus be characterized by their special families and species; the demarcation lines provided by the evolution of organisms are of almost worldwide significance.

N.S. Shatskij (1937) seems to have introduced the term neocatastrophism to describe certain trends in contemporary geology. This geological neocatastrophism will not be considered here. We are concerned solely with the palaeontological sphere to which Stepanov has transferred the term neocatastrophism. By the nature of things he digs deep into our stratigraphic conceptions and methods, so that a presentation of these issues to a geological forum ought to be wholly relevant.

The term neocatastrophism seems acceptable so long as it is made clear that the ideas it portrays have hardly anything to do with Cuvier's catastrophism. Since nowadays we all uncompromisingly accept the evolutionary standpoint, the theoretical background is quite different. Yet in characterizing the factual position one may speak quite simply of catastrophism. Thus extinction can never be anything but a sudden, drastic event; an individual, a species, a genus, a family or a phylum is either alive or extinct. To an individual or a phylum alike death is a catastrophe, even if it has already been introduced over a certain period of time through disease, degeneracy or the like. The decisive question is whether such catastrophes display in the Earth's history a simple statistical distribution or occur massively, as well as in different phyla, at certain times.

In any case faunal discontinuities, as understood by us, involve not just the dying out of old, but also the more or less sudden emergence of new phyla. This phenomenon can no longer be successfully accommodated under the term catastrophe in the true meaning of the word: it should rather be described as *anastrophe*.

The questions arising from faunal jumps have in recent years been a subject of lively discussion in various quarters. Stepanov apart, numerous objections have been raised elsewhere to their reality and interpretation. Now, since I have been declared spokesman of

neocatastrophism, it may be appropriate for me to give a brief appraisal of such work as has come to my notice.

II. The Precambrian-Cambrian Faunal Discontinuity

The faunal discontinuity on the divide between the Precambrian and the Cambrian is certainly the most radical and the most discussed in the history of the Earth. Already a 100 years ago Darwin was looking in vain for an earlier fauna antecedent to the Cambrian from which the latter could have been derived by gradual transformation. He sought to explain its absence by assuming that at the beginning of the Cambrian the distribution of land and sea could have been completely different from what it became later, and consequently, the oldest strata with the expected ancestral forms of the Cambrian fauna would not be accessible to observation. Alternatively, a thorough metamorphosis of the rocks might have completely destroyed the oldest faunas. Similarly J. Bergeron (1892) assumed that the so-called primordial fauna must have been preceded by an earlier fauna, which contained the precursors of the oldest fauna bequeathed to us. There was, however, no hope of ever finding these, as they were supposed to have been destroyed without a trace by the metamorphosis of the corresponding strata.

We have known for some time that these explanations are invalid. Abundant Precambrian strata are known that do not differ in any way in their metamorphic grade, and so in their potential capacity to retain fossils, from Cambrian and post-Cambrian rocks. Moreover, these Precambrian strata have for the most part originated in the same geosynclines or other sedimentary basins as were the sites of formation of the older Palaezoic rocks; thus there was no basically different distribution of land and sea.

This finding aroused new hopes of discovering precursors of the Cambrian faunas, and great efforts have been made in this direction everywhere and especially in North America by C.D. Walcott. As is well known not much has come of it all. Many cases have been described where organic origin was suspected; but further examination has almost invariably shown that these were either purely inorganic structures or, if they were actually fossils, they did not originate in the Precambrian (Schindewolf 1956).

The situation today is exactly the same as a hundred or more years ago. We are confronted with the Cambrian fauna in isolation and without ancestry; no precursors of the Cambrian trilobites, brachiopods and other animal phyla (see Fig. 1) have been found. In addition, the Precambrian rocks are not wholly devoid of fossils. We will leave here out of consideration Collenia and other stromatolites that occur in the Precambrian, as well as in the Cambrian and in younger strata in a consistent manner. Animal remains, especially tracks and casts of soft-bodied animals, are also found, however, and show that even such transient structures could be preserved in Precambrian rocks. A. Seilacher (1956) has made a comparative study of trace fossils from the Precambrian and the Cambrian and established that they display profound differences in the degree of differentiation.

The most important finds of recent years in South Australia (Ediacara) have been published since 1947 by R.C. Sprigg and M.F. Glaessner. They come from strata to which L.C. Noakes (1956, p. 223) and M.F. Glaessner (1959, p. 530) ascribe on good evidence a late Precambrian age. The surprisingly rich fauna consists, in so far as it can have been interpreted up to date, of medusids, polychaetes, annelids and doubtful octocorals, and so of wholly soft-bodied organisms, which have found excellent conditions of preservation in thinly foliated, fine-grained quartzites. Yet there is not the slightest trace of trilobites, brachiopods and other exoskeletal organisms. Although the form described as *Spriggina floundersi* Glaessn and classified as a polychaete may indicate, according to Glaessner (1958, p. 187), the formation of a primitive arthropod head shield, a chitinous or calcareous exoskeleton, such as characterizes trilobitomorphs, is lacking.

Thus the great gap, consisting in the absence of a fauna ancestral to the Cambrian life world, has not been bridged by the South Australian finds, and contrariwise has been only

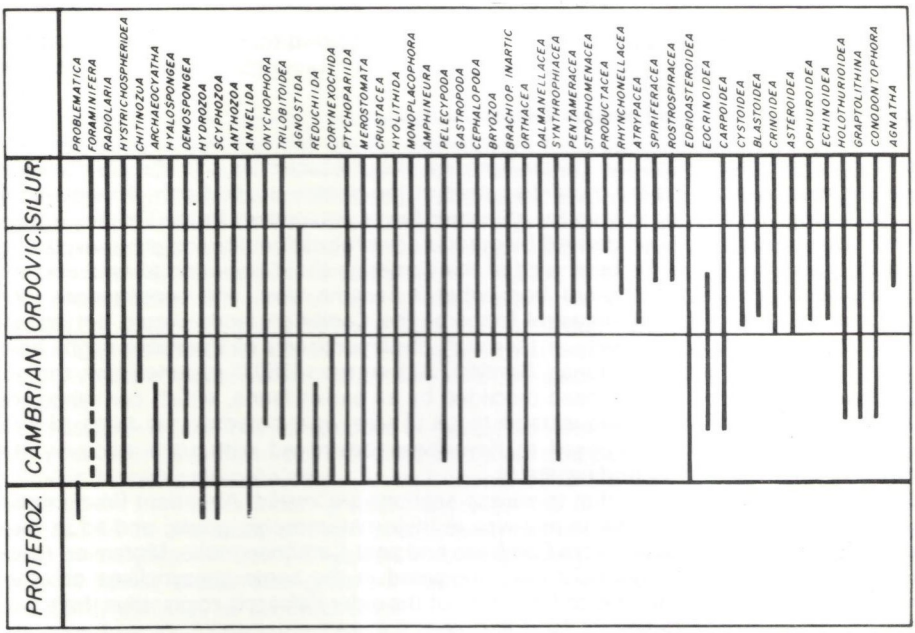


Fig. 1. The faunal turn at the basis of the Cambrian.

underlined by these. It teaches that good conditions of preservation existed even for the most delicate, soft-bodied organisms in the Precambrian, and that resistant hard skeletons ought *a fortiori* to have been preserved if the corresponding animal forms had been present.

Nevertheless, loud voices have recently been heard that seek to cast doubt on and rediscuss the reality of the sharp division between the Precambrian and the Cambrian living worlds. W. Simon (1958, pp. 820 ff) maintained that the higher organized faunas of the Precambrian that could be regarded as precursors of the Cambrian life world would be restricted to the geosynclines. They would thus be placed outside our knowledge, as the rocks of the Precambrian geosynclines were "preserved in an almost totally metamorphosed state". In this way a long-rejected argument enjoys a resurrection.

The Precambrian geosynclines of the Cordilleras, the Appalachians, the Caledonides, of North Greenland, the Urals, Altai, the Yenissei ranges, the North Korean, the South-West African Nama geosyncline, as well as the Australian Adelaide and Amadeus geosynclines, etc. include late Proterozoic strata which display *no* metamorphic alterations. There exist in part continuous Precambrian rock series where it is often difficult or impossible to draw a dividing line on a petrographic basis. The great thicknesses of the sediments extensively interstratified with vulcanics, and their gradual transition to Cambrian strata of unequivocally geosynclinal character leave no doubt that we have here geosynclinal deposition. Yet they have nowhere provided the expected precursors of the Cambrian fauna, but always only the already mentioned faunas of a completely different character.

It was further assumed by Simon, as well as by K. Sdzuy (1960), that the more evolved faunas of the Precambrian, of whose existence they were convinced, were confined to a smaller area than their Cambrian successors. Their discovery would thus be largely a matter of accident, thus adequately accounting for the gap in our knowledge. It may well be true that the range of occurrence of at least the *benthonic* fauna of the Precambrian was actually

smaller than that of the Cambrian. I incline, however, to envisage the Precambrian faunas as predominantly *planktonic,* so that such limitations would hardly apply.

In other respects, however, I cannot accept the arguments as justified. Without any doubt the said geosynclines, as well as the broad shelf regions, which Sdzuy regards as the most favoured habitats, have been investigated for fossils in the Precambrian rocks with at least equal attention as in the Cambrian, and somewhere or other the expected faunas ought to have been discovered in the end. In actual fact Precambrian faunas have indeed repeatedly come to light, but they have a composition quite different from that expected.

Thus in my opinion we cannot escape the conclusion that on the divide between the Precambrian and the Cambrian there was a relatively sudden and thorough-going transformation of the animal kingdom, in which durable hard parts were deposited for the first time, as has latterly been assumed by P.E. Cloud (1948), W.F. Whittard (1953), O.H. Schindewolf (1954, 1956) and A. Seilacher (1956), as well as other authors already before them. If things were in reverse, if we knew armoured and shell fossils only from the older strata, with possibly less favourable conditions of preservation, and soft-bodied ones solely from the younger strata, then it might be hazardous to assume a faunal break. As it is, thought, the available facts should be unequivocally conclusive.

K. Sdzuy (1960) describes these ideas as "anactualistic" hypotheses, as the sudden recasting of a substantial part of the living world has to be considered an event without any certain parallels; such ideas are said to be based on unproven assumptions. I regard both these positions as false. Even in the more recent history of the Earth we have examples of profound transformations in the composition of the faunas, which involve no risk of confusion due to insufficient preservation, lack of exposure or the like. My various publications on this subject (Schindewolf 1950, 1954a, 1954b, 1956) are left unconsidered or at least unmentioned. With regard to the emergence of new stocks the Permian-Triassic and Cretaceous-Tertiary boundaries afford pictures altogether comparable to that at the lower boundary of the Cambrian (see Figs. 1-3). And one can hardly speak of "unproven assumption," as my interpretations follow closely the empirical facts and seek to explain these. In any event the facts themselves are obviously not affected by the possibility of their causal explanations being wrong.

The remaining arguments presented by Sdzuy are recognized by me as largely justified, only they appear to me to miss the point. It seems correct that the Cambrian trilobite faunas do not appear everywhere at the same time, i.e. with the same zonal fossils, more particularly in view of the work of P. Hupé (1953, 1960). Thus the appearance of "the first trilobites" can by no means be used to date the beginning of the Cambrian. On the contrary, we have to fix the lower limit of the Cambrian by the appearance of the oldest representatives from the realm of ollenelids (or stratigraphically equivalent trilobites). According to our present information this would be the zone of *Fallotaspis tazemmourtensis* Hupé. That this zone may be represented elsewhere by rocks devoid of fossils or by a facies with a different fauna is nothing unusual; enough of similar cases are known from more recent strata.

Since the trilobite-bearing strata of the *Fallotaspis* stage (Amouslekian) contain intercalations of archaeocyathid limestones, or may be wholly replaced by an archaeocyathid facies without trilobites, the similar archaeocyathid limestones will have to be assigned to the Cambrian on the basis of the *tazemmourtensis* zone. They must be provisionally included in this zone unless some different, still older trilobites are found in them or their equivalent rocks. In any case I consider it incontestable that the lower limit to the Cambrian is to be drawn here and not somewhere in the middle of the trilobite series, or at the base of the middle Cambrian, as proposed by H.E. Wheeler (1958, p. 20) and K. Sdzuy. The Cambrian is the division where the dominance of the trilobites begins, and this should be adhered to, even if for the time being it is not possible to fix quite rigidly the lower limit.

We must not lose sight of the wood for the trees! What is certain is that as from a certain point of time in the history of the Earth we have trilobites in many localities of the Earth and that a little before then they were still absent. If it seems impossible for the time being to fix-

the corresponding transition point with sufficient accuracy, one may provisionally take a certain intermediate range within which the development of the trilobites has been completed and look to the future to provide evidence for that. Without a shadow of doubt, however, this transition period has been extraordinarily short as compared with the ensuing slow development of the trilobites in the Cambrian, Ordovician, Silurian, and so on. The whole cycle of evolution of the trilobites covers over 300 million years; yet the period to be assigned to the emergence of the trilobites would be a few million years, as only a few zones may be assumed to be temporarily missing.

More than that should not be claimed, nor has ever been claimed by me. The faunal discontinuites must be measured on a geological scale, and they then will reveal a powerful acceleration of evolution within this co-ordinate framework, so that we may speak of "sudden" transformations. This is not conceived in the terms of a natural catastrophe that has befallen the whole of the Earth with great suddenness and absolute simultaneity.

The trilobites have not dropped out of the sky in a single day either. They have obviously evolved from other forms, presumably certain polychaetes[1], but this evolution must have been completed in a relatively short time. Such behaviour is known to us from the early development of many stocks. I have given examples of this *inter alia* in my study of the time factor (1950, pp. 60 ff). It may here be recalled that according to G.G. Simpson's estimate the evolution of the Chiroptera would have to have started already before the origin of the Earth if the structural plan of this order had been formed at the same slow rate as can be followed from the Eocene onwards in their minor further development. Other examples of the sudden emergence of many classes, orders, super-families, etc, as well as of further divergence reaching down to the roots, have been lately presented by Nicol, Desborough and Solliday (1959).

Like Stubblefield (1959, pp. 149, 142) among other authors, I have also proposed (Schindewolf 1954a, p. 168; 1955, p. 493) that the trilobites have originated through a relatively late acquisition of an exoskeleton from forms that were already highly differentiated, but were not trilobites yet, as the exoskeleton is part and parcel of the structural and functional scheme of the trilobites. At the same time I have cited as a comparable model (1955, pp. 192-193) the more primitive species *Poraspis* of the Agnatha, which also had an exoskeleton, but according to A. Heintz clearly did not acquire it ontogenetically until very late after a long unarmoured larval stage and so shows that it could do without an exoskeleton as well. (The earliest representatives of the vertebrates and their ancestral forms will almost certainly have been planktonic, non-skeletal organisms, as exoskeletons are simply not to be found before the late Ordovician, and the early forms of the benthonic series are equipped precisely with especially strong protective armour.) Thus it may be significant in this context that according to new publications by A.R. Palmer and H.B. Whittington precisely among the olenellids, and unlike the later trilobites, the protaspis stage seemingly had no hard skeleton yet.

Unlike Sdzuy I am, further, not of the opinion that the "conquest of the sea bottom" by the Cambrian fauna must have taken a long time. The comparison drawn by him with the conquest of dry land by animals and plants appears to me wholly mistaken, as this required extensive pre-adaptation, readjustment and organizational re-arrangement. None of this was involved in the Cambrian, as the seabed had already been conquered in the Precambrian. A suitable marine fauna had already been there and did not need to become adapted to a new habitat. Nor can I accept the parallel to the belemnites drawn by him. The closed deployment of the belemnites in the narrower meaning of the term really began in the Lias; the Carboniferous "belemnites," as well as the Triassic aulacocerates and atracites are not the directly antecedent stages of this phylogenetic cycle.

1) TIEGS & MANTON (1958), on the other hand, have recently expressed the view that the arthropods ought not to be derived from the annelides, but from some other Precambrian group, which has left no traces.

Our problem has been approached from a different angle by E. Bederke (1960, p. 318). He quotes from the literature a number of absolute age determinations, which assign an age of 1,100-1,600 million years to some rocks regarded as late Algonkian. From this it would follow that "in North America and North Europe a period of at least half a thousand million years preceding the Cambrian remained geologically unrecorded". This would shed "a completely new light on the geological and palaeontological problems associated with the Proterozoic-Palaeozoic transition".

Where the error lies, I am unable to say, but I am convinced that there is an error either in the calculation or in the interpretation. We know numerous profiles that extend quite uninterrupted, without any marked petrographic breaks, over the boundary, from the Proterozoic into the Cambrian, and I consider it wholly inconceivable that this could conceal gaps of the time order of the whole of the post-Proterozoic history of the Earth. Has, then, this period of 500 million years been completely lost, without leaving any trace at all; has nothing happened during that time? This cannot be seriously assumed, and I am, accordingly, of the opinion that we are not entitled to expect any such lost intervals of time.

Moreover, it has been shown by the recent work of Polkanov and Gerling (1960) and M.S. Krishnan (1960) that the allegedly missing span of time is recorded without any gaps in absolutely dated rocks and numerous geological events in the Baltic Shield and in India respectively. Polkanov and Gerling (1960, p. 188) conclude that "there never was an enormous Precambrian hiatus". We further see from a report by N.H. Magnusson (1960, p. 140) that the absolute dating has given ages of between 964 and 985 million years for the Swedish Jotnian and Eocambrian, and so ages that are likewise much too high, beyond all expectation. Magnusson says this is "absolutely impossible" and looks for a plausible explanation of this discrepancy between the absolute dating and the geological findings.

III. The Permian-Triassic Faunal Discontinuity

An important report has recently been published by R. Trümpy (1960) on the Permian-Triassic boundary, describing the conditions in East Greenland. Newly discovered profiles which span the turning point have shown that rocks with a fauna bearing a Permian stamp are intercalated at the base of the Trias in a rock series with *Otoceras, "Glyptophiceras," Ophiceras,* etc. The common fauna consists of brachiopoda, bryozoa, crinoids and corals as stragglers from the benthonic life of the Permian. Consequently, marine faunas of Permian and Triassic character were living here for a certain time side by side and appear to us intertwined. This does not affect the possibility of drawing a clear demarcation line between the Permian and the Triassic; the characteristically Permian ammonoid species of *Cyclolobus* and *Medlicottia* had already been extinct in Greenland too before the appearance of *Otoceras* and the ophicerates.

From this Trümpy (1960, p. 100) concludes: "Owing to this survival of the Permian benthos into a time when ammonites of Triassic character already existed, the faunal divide between the Palaeozoic and Mezosoic must necessarily lose some of its absolute sharpness". It would be less abrupt than I at one time inferred from the profiles of the Salt Range investigated by me. This is undoubtedly correct. Yet this does not, of course, abolish the existence of the faunal division as such, nor does Trümpy himself contend as much. On the contrary, he is completely convinced of the existence of the Permo-Triassic faunal jump, and generally has "no doubt about the existence of relatively brief geological intervals during which the evolution of the animal world progressed at an accelerated rate".

Such a case is incontrovertibly present at the Permo-Triassic boundary. It must further be borne in mind that the corals, brachiopods and bryozoa of Permian type which overlap into the Trias belong to purely Palaeozoic stocks that already originate in the Ordovician and cover a long life span of some 270 million years. On the other hand, the ophicerates, which also introduce the prolonged evolution of the ceratites, phyllocerates, etc. characteristic of the Mesozoic, likewise represent a significant turning point. As compared with this the overlap of the two faunal communities in a zone of the lowest Triassic is of only a very short duration,

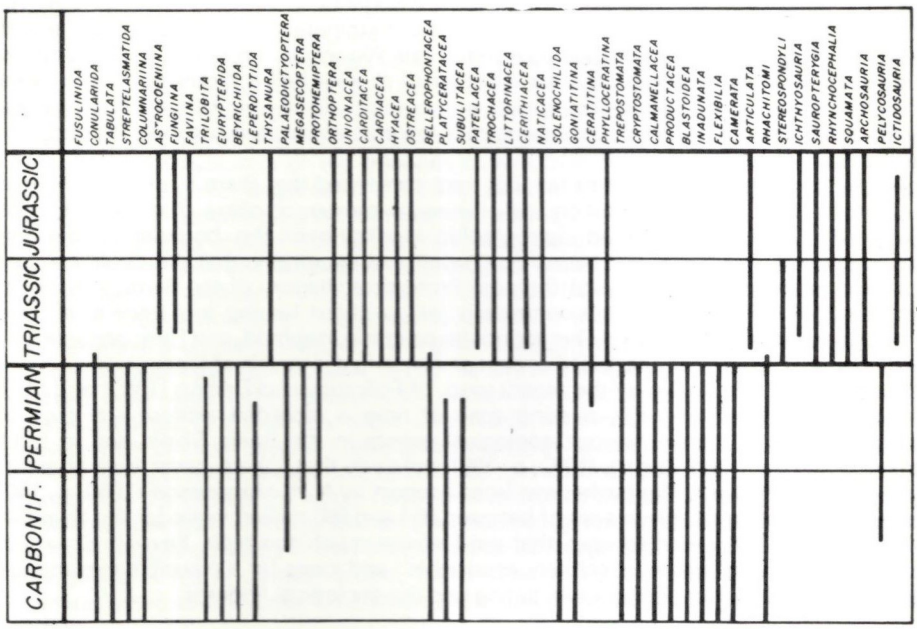


Fig. 2. The faunal turn at the Permian/Triassic boundary.

and so does not contradict the idea of a geologically speaking very rapid and profound faunal transformation (Fig. 2).

In one respect, however, Trümpy's findings appear to me important and welcome: they refute the possible objection, which has already been raised, that the Salt Range profiles are so incomplete as to yield an apparent faunal jump. There would have been a gradual evolution, but it would be confined to a gap unrecorded in the rocks. The profiles of the Salt Range may, in actual fact, include interruptions in sedimentation, even though these are unrecognizable in the rocks[2]; but I have already said before that this does not decisively affect the reality of the faunal turning point. We now have in the demonstrated intermeshing of the "Permian" and Triassic fauna direct proof that there has been no time gap of the required long duration between the two faunal complexes. Nor can it be any longer maintained that the cause of the faunal break lies in a simple change of facies.

D.L. Stepanov (1959a) also mentions finds of Permian faunal elements in the lower Triassic of Trans-Caucasia and other regions. Conversely many Mezosoic species occurred already in the upper Permian. According to J.N. Popov Permian nautiloids would extend into the Triassic, and I have myself mentioned that a branch of cephalopods crosses the Permo-Triassic divide in unbroken development. All this is true and not contested by anybody. We know, more particularly from the work of A. Kieslinger and B. Kummel, that the Triassic nautiloids belong partly to stocks whose evolution had begun already in the Carboniferous. The decisive turning point for the nautiloids lies higher on the Triassic-Jurassic boundary, and sub-

2) The completeness of any given profile can hardly ever be rigorously demonstrated. It escapes assessment what might be interposed in the joints between the layers. On the whole, however, they would correspond to only brief interruptions in sedimentation, and so be in the nature of a time lapse rather than indicate the loss of complete stratigraphical zones and stages.

stantially coincides with the dynastic change-over from the ceratites to the ammonites proper.

There are still further stocks and evolutionary series which cross the Permo-Triassic boundary without fundamental changes. But their presence is no proof against the existence of other stocks that have been profoundly affected, becoming part extinct, part newly formed. And it is precisely these especially characteristic groups that determine, on the one hand, the Palaeozoic and, on the other, the Mesozoic character of the corresponding strata. Chosen for our tables have been such animal groups as either die out or appear for the first time, whose behaviour forms the basis of faunal discontinuities. This, though, must not be understood in the way that there have been no cases at all of persistence beyond the critical limits.

Moreover, the faunal discontinuities would stand out even more clearly if, in addition to the already considered categories of a higher order, we included also those of a lower order, yet of characteristic significance. Thus the appearance of the placodonts should also be taken into consideration for the Triassic, and the dying-out of the mosasaurs, inocerami, exogyrids, gervilleids, globotruncanids and much else for the Cretaceous-Tertiary boundary.

We, therefore, nowise seek to deny — to emphasize this clearly once more — the existence of many links between the faunas of the individual eras. What distinguishes fundamentally the "neocatastrophism" as proposed by myself from Cuvier's catastrophism is that we do not assume any complete, worldwide destruction of entire life systems followed by new creations.

IV. The Cretaceous-Tertiary Faunal Discontinuity

The events on the Cretaceous-Tertiary divide have often been judged somewhat onesidedly from the point of view of the extinction of the dinosaurs. The causes to be taken into consideration in this connection have latterly been discussed by A.F. de Lapparent and

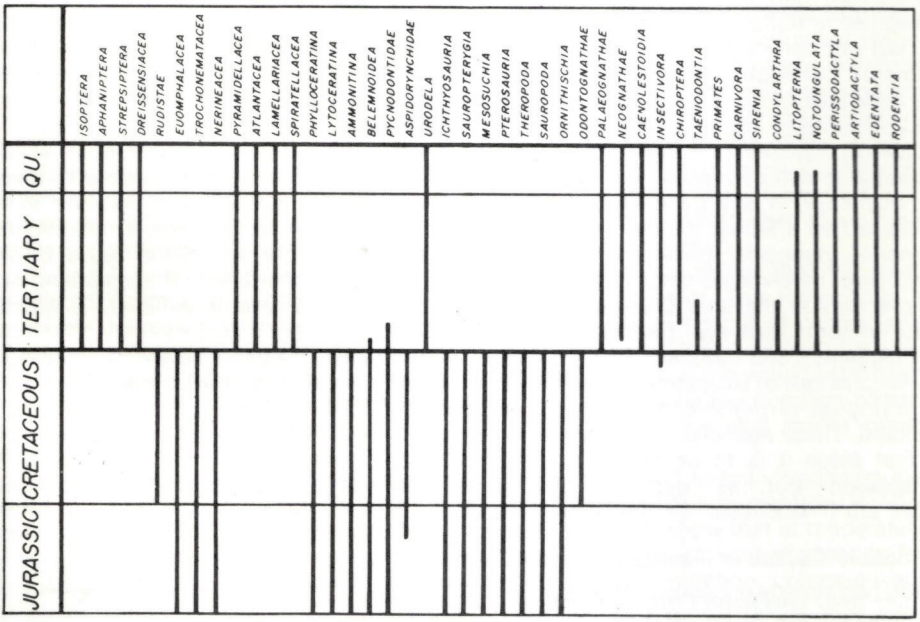


Fig. 3 The faunal turn at the Cretaceous / Tertiary boundary.

R. L'Avocat (1955, pp. 939 ff) and A. Romer (1961). Yet the dinosaurs represent only one aspect of the much wider extinction process and the profound change in the composition of the faunas which I have previously attempted to outline in full (1950, pp. 9, 98 ff). It will be understood, however, that conclusions regarding the causes of this faunal jump can be drawn, if at all, only from the overall picture (Fig. 3).

Romer's exposition, however, is of great interest to us, as he too regards all the previous explanations of the extinction of dinosaurs as inadequate. In his opinion the suggested conditions may possibly make understandable a certain reduction in the number of forms of the dinosaurs, but hardly their sudden, complete extinction. He rejects that "explanation" that the placental mammals, which blossomed out on the Cretaceous divide, had eaten all the dinosaur eggs and thus caused the extinction of the phylum. This contention cannot, in fact, be taken seriously; for on this view the mammals ought to have eaten also all the ammonite and belemnite eggs, while, on the other hand, they had spared the eggs of crocodiles, lizards and tortoises, which were more readily accessible to them on dry land.

Romer quotes another version: "The Rocky Mountains had killed off the dinosaurs," by which he means that this orogeny could actually have reduced the area of the lowlands with marshes and lagoons, altered the climate, the wind directions and patterns of rainfall. Although climatic change may have been a contributory factor, it could not account for the sudden disappearance of the dinosaurs, numerous and dominant at the end of the late Cretaceous. Indications of any noteworthy drop in temperature seem to be lacking, nor would it be fatal to reptiles unless spectacular frost had intervened: even then, however, it would be possible to weather the winter in protective quarters.

Yet, according to R. Bowen (1961), a drop in temperature was recorded in the Maastrichtian: on the other hand, an equally strong drop in temperature had occurred already in the Aptian and an even more important one in the Cenomanian, which had been readily withstood by the dinosaurs. The reverse idea of heat death previously entertained by R.B. Cowles, stands in contradiction to the actual temperature conditions. Moreover, any marked rise in temperature would primarily affect the small reptiles and cause their extinction, but not particularly the dinosaurs of great size. To this must be added two further arguments that appear decisive to us: 1. There were no Rocky Mountains everywhere in the wide total area of distribution of the dinosaurs; 2. It is not apparent that the effect of the Rocky Mountains could be applied to marine habitats.

Epidemic diseases must be eliminated, as these would have to have conspicuously struck the dinosaurs and pterosaurs, but not the crocodilians, which were closely related to them. Nor, obviously, is any generalization possible, as it cannot be assumed that the same epidemics had affected the marine ichthyosaurs, sauropterygians, mosasaurs, ammonites, belemnites, nerineids, inocerami, etc. A change in the flora cannot be the cause of the extinction of herbivorous dinosaurs either; because the floral discontinuity is antecedent, and it is precisely in the later Cretaceous that the herbivorous dinosaurs exhibited a greater variety of form than ever before.

De Lapparent and Lavocat (1955, p. 945) see the causes of the extinction of the dinosaurs in minor changes of temperature, humidity of the air and cloudiness, a reduction (of the area) and drying-up of marshland, which the reduced adaptability of the dinosaurs could not withstand. These agencies, however, have been justly rejected by Romer as inadequate. In the first place it is to be borne in mind that the dinosaurs must not be considered in isolation but as part of the global complex. Yet the stated external factors are meaningless for the marine faunas

V. Possible Causes of Faunal Discontinuities

I too had already previously (1950, pp. 98 ff; 1954a, pp. 170 ff) discussed similar possibilities and reached the same negative conclusions as Romer. Since faunal discontinuities are universal phenomena, they must arise from *universally active causes*. This has compelled me to look for agencies that would (1) have worldwide effects and (2) could extend to the totality

of biotopes in the sea, on dry land, in freshwater and in the air, as well as to stocks of most varied habitats and ways of life.

Since 1950 I have favoured the hypothesis that sharp fluctuations in the high-energy cosmic radiation reaching the Earth should be considered among possible causes. In 1954 (b) I analysed in more detail this idea and the corresponding working mechanism. I proposed that, on the one hand, the direct impact-effects of ionizing radiation should be considered, and, on the other, especially the increased generation of radioactive isotopes, which would become incorporated in the living organic matter and the molecular compounds of the chromosomes. Here they would unleash a twofold mutagenic activity, through ionizing radiation, on the one hand, and by the liberation of electrons in the decay of the isotopes on the other. Experimental proof is available for such a sequence of processes.

Similar ideas have recently been voiced, if seemingly in less precise form, and clearly independently, by several Russian research workers. We will mention, partly from quotations, as the original publications are not accessible, N.P. Dubinin (1956) and V.I. Krasovkij & I.S. Shklovskij (1957), who regarded, in agreement with us, an increase in cosmic radiation as the cause of the catastrophic turning points in the evolution of the organic world. E.A. Ivanova (1958) sought to establish a connection between the faunal discontinuities and the migration of radioactive elements.

Quite recently Dyssa, Nesterenko, Stobas & Shirokov (1969) have been concerned with faunal discontinuities. They affirm their reality, emphasize their universal character, extending to the living worlds of the seas and dry lands simultaneously, and regarded the conventional explanations as unsatisfactory. They too envisage increased radioactivity, which they, however, ascribe to intensified vulcanism. The radioactive products of these volcanic eruptions contaminated the atmosphere and hydrosphere and caused the extinction of numerous stocks. I am afraid, however, that the time correlation needed to support these views is lacking. Thus the arctic Thulean basalts, the Deccan traps, the great lava sheets of Columbia and Patagonia of an Eocene or mostly Miocene age are in any case too recent to have been responsible for the faunal transformation at the Cretaceous-Tertiary boundary.

In criticizing my ideas D.L. Stepanov (1959a) has raised the question whether it is unavoidable to assume universally active causes to understand the extinctions and the faunal and floral jumps. For, he says, Darwin's theory of selection explains the extinction of forms as a natural process. True, but the faunal discontinuities involve not merely the "normal" continuous dying out of individual species or groups, such as has been going on steadily throughout the history of life. On the contrary, their distinctive feature is mass extinction, and the coincidence in time of the universal extinction of numerous stocks of the most varied biotopes. The question forming the starting point of our deliberations must, therefore, be answered, in my opinion, absolutely in the affirmative. Today it is no longer advisable to invoke darwin's geological and palaeontological arguments as proff; after all we have advanced considerably during the 100 years that have elapsed since then.

Stepanov further objects that massive experimental material shows that the mutations mediated by ionizing rays are predominantly deleterious or lethal. This too is true, and is precisely the reason why we make them responsible for the dying out of numerous phyla. Some advantageous, constructive mutants must, however, arise as well from time to time; for otherwise any advance in evolution would be impossible and all life would have been long extinguished. If the rate of mutation is increased so must also be the numbers of such advantageous mutants, which would open new possibilities to the vital stocks capable of development.

There are indeed some indications that in special conditions cosmic irradiation exerts a positive, stimulating influence. Further the experiments carried out on plants by P. Michaelis and R. Kaplan (1953) with the radioactive isotopes P32 and S35 show that at moderately high mutation rates some forms display low survival rates and frequent disturbances in fertility, but others, contrariwise, maintain, despite very high rates of mutation, comparatively high rates of survival and a full, or only slightly reduced, fertility. Organisms with the latter behaviour could be of evolutionary importance for the future. It is obvious and calls for no further comment that selection and many other factors must be involved. All we are con-

cerned with here is suggesting initial processes that might set the mechanism in motion.

Climate, to which Stepanov ascribes great importance, must clearly be one of the contributory factors. But I am unable to see a triggering effect in it, or in the ice ages that have been frequently invoked. Land glaciations have never extended to all the continents; the Pleistocene Ice Age was of only minor importance for the southern continents; the Pleistocene Ice Age was of only minor importance for the southern continents. According to A. Romer (1961, pp. 202 ff) the extinction of numerous Pleistocene mammals has not been climatically determined. They partly survived to sub-recent times, had outlasted all climatic changes and did not die out till the end of the Ice Age. According to Romer they are supposed to have been exterminated by Man, which would take us back to Steinmann.

The glaciations have hardly any effect on marine biology. During the Permian ice age the invertebrate faunas, including the highly sensitive corals, nowhere show any profound changes, even in the seas that lay close to the glaciated terrains; they continued to live unaffected. Recently it has even been statistically demonstrated by A.H. Muller (1961, p. 91) that the "great ice ages of the Earth have had no lasting effect."

Upon rethinking the problem and re-examining the literature, the intrusion of ionizing radiation still seems to me to provide the most plausible explanation of the faunal discontinuities. But the issue of cause is independent from the idea of neocatastrophism. It is based on the faunal jumps, or the relatively short periods of profound transformation in the biosphere. These are facts, which in my opinion are nowadays no longer open to serious doubt. Thus "neocatastrophism" is simply a term describing actual facts, and not any world view or some special philosophical system of Earth history.

Added in Proof (28th January, 1963)

Since the completion of this manuscript in the summer of 1961 several further publications have appeared on the controversial issues broached here. It is not possible to consider them in detail; to some extent this is superfluous because the various interpretations dealt with in these publications, which always follow the same tracks, have already been implicitly assessed here.

We will mention as an important contribution the Presidential Address by N. Newell (J. of Paleont, 36, pp. 592-610). Although published as early as 1962, it could already make use of the manuscript of this paper and publish in advance two of my tables from it. Newell reaches the conclusion that eustatic fluctuations in the sea level cause gaps (paraconformities) in the profiles which constitute the main initial cause of the faunal discontinuities, and more particularly that on the Permo-Triassic boundary. I cannot agree with him about that. According to a statistic compilation by A. Cailleux (*Cahiers géol.*, Nos. 58-61, pp. 558-560, Paris 1961) on the basis of numerous profiles from different regions of Soviet Russia, the lowest percentage of gaps in the strata in the whole of the history of the Earth would occur precisely on the boundary between the Permian and the Triassic! That layers and individual zones are missing in apparently continuous, fully concordant profiles, as Newell shows on examples, is generally known. But, as I have already previously objected (1958, p. 275), how large would these gaps have to be to enable us by their means, to reinterpret the profound, abrupt faunal jump as a gradual, steady transformation of the fauna? This cannot be done by omitting a couple of zones!

Other attempts at explanation (K.Beurlen 1956 and lately A.G. Fischer 1963, Palaeoclimates Conference, Newcastle) which seek to trace the faunal discontinuity on the Permo-Triassic boundary back to greatly reduced salinity of sea-water overlook the fact that groups of brackish-water animals, such as eurytrepids, and terrestrial forms, such as insects and tetrapods, were also greatly affected by the critical event (see Fig. 2). Possibly one could maintain that the reaction of the insects was less strong than might be expected from our hypothesis of cosmic radiation. It must, however, be borne in mind in this connection that the resistance of insects to radioactive radiation is about ten times greater than that of human beings and other organisms.

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GLACIATIONS, BIOLOGIC CRISES AND SUPERNOVAE

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Summary and Introduction

The organic evolution of our planet during the Phanerozoic is characterised by sudden mass extinctions of various groups acompanied or followed by the sudden proliferation of forms belonging to the same or to other groups. During the Precambrian and at the Precambrian-Cambrian boundary discontinuities are distinguished by the sudden expansion of many forms, not preceded by extinctions. Both types of crisis must be regarded as revolutions in the history of Life.

An attempt is made here to demonstrate that the biologic revolutions are correlated in time with glaciations or temperature minima and must have been provoked by the same agent. It is contended that glaciations were caused not by terrestrial events but by decreases in insolation, whereas the biologic crises were due to increases of hard ionizing cosmic radiation which strongly affects the mutation rate. Such increases in cosmic radiation are postulated to be generated by flashes of Supernovae in the vicinity of the Solar System; the nebulae formed during these events would have shielded the solar radiation causing a decrease in temperature at the planet's surface.

It is argued that the Earth and the Life on it are not closed self-developing systems but constitute a part of the Cosmos. Solar rays together with galactic and cosmic rays are life-giving; it is impossible to imagine the appearance of Life or its evolution without the effect of these rays. When examining the ecological aspects of Life on Earth one must bear in mind that the environment, sensu lato, embraces the whole Universe.

This paper is primarily addressed to geologists and thus certain information from astrophysics and radiation genetics is included.

Acknowledgements

A talk on the subject of this paper was given at the sitting of the Scientific Council of VSEGEI in January 1974 in Leningrad and also at the meeting held in February 1974 in Moscow on "Cosmic factors and evolution of the organic kingdom". These problems seem to arouse much interest now, and the Moscow meeting was one of the symptoms of it. I thank everybody taking part in the discussion and in particular A.V.Khabakov, P.N.Kropotkin, V.P.Nekhoroshev, and V.N.Shimansky for fruitful discussion and valuable remarks. I also thank Mrs. V. Grudina for translation of this paper.

I. Glaciations and Epochs of Climatic Cooling

Of the several major glaciations that are inferred from the stratigraphic record, the oldest occurred during the Mesoprotozoic, about 2500-2300 MY ago (Salop, 1973). Proof of this lies in fossil moraines (tillites and related formations) reported from North America (Huronian and Animikie Supergroups, Hurwitz and Libby-Creek Groups), from South Africa (Government-Reef and Griquatown Formation), from Europe (Sariolian Group of Karelia), from South Asia (Bijawar Group of India), from Western Australia (Whitewater Group) and probably also from South America (Sabara Formation). The Huronian Supergroup in the south of the Canadian Shield presents this evidence most unambiguously. Three tillite levels are reported from that region (Ramsay Lake, Bruce and Gowganda Formations), corresponding to three glacial periods separated by epochs of warm or even hot climatic regimes which lasted some tens of millions of years.

Younger Precambrian glacial deposits, considered here to belong to the Epiprotozoic Era, are reported from numerous localities on every continent, distributed irrespective of latitude, wherever the poles were located in the past (Salop, 1973; Chumakov, 1975; Harland, 1976). In areas lacking tillites, coeval strata attest to the influence of a cold, almost glacial climate. Two principal tillites are dated isotopically at 870-820 MY and at about 680 MY.

The next major glacial epoch occurred in the Early Cambrian, probably about 570-560 MY ago. Deposits associated with this glacial event are conspicuous in the Schwartzrand Formation of the Nama Group in South-West Africa. Glacial formations in the Western Sahara (the Colomb Béhar?), in Canada (the Yukon River Basin) and in the north-east of the USSR (Pri-Kolyma region) probably belong to the same stratigraphic level. Indications of a glacial environment may also be observed in rocks of the Lower Cambrian base in southeastern Sweden (Vortisch, 1973). The Early Cambrian glaciation does not appear to have been very extensive, but it was probably associated with global cooling.

Younger glacial formations are Upper Ordovician in age, mainly associated with the Ashgill stage which is dated at 450-440 MY. Tillites belonging to this phase are widespread in the Sahara, and also in Morocco, South Africa, North America (Nova Scotia), and in Europe (Normandy, Thuringia, Spain, Galicia) (Harland, 1972). Glacial formations also occur in Upper Devonian sediments in South America (northeast Brazil, Argentina) and on Mallorca in the Mediterranean.

The fairly well expressed Upper Paleozoic glaciation (Upper Carboniferous or Carboniferous/ Permian boundary) is reported from many areas of the Southern continents (the "Gondwana Glaciation"), where it is characterised by the well-known and extensive (500 x 140 km) Dwyka tillites occurring in the lower part of the Karroo group of South Africa and by the synchronous tillites of South America, South Australia, India, Antarctica and Arabia (Wanless and Cannon, 1976). Paleontological evidence of climatic cooling at the Carboniferous-Permian boundary is known farther to the north, in Afghanistan for instance. The age of sedimentary strata embracing tillites is in the range of 300-280 MY.

Marine-glacial and fluvioglacial formations are also recorded in the Upper Permian of New Zealand and the north-east of the U.S.S.R. (Bogdanov, 1967; Mikhaylov et al., 1970). Deposits of this type are not yet known in other parts of the world. The Late Permian is dated at 260-240 MY, in the accepted geochronological scale.

The most recent major glaciation, the Pleistocene Ice Age, which occurred in polar and middle latitudes of both hemispheres, was initiated about 1.8 MY ago and terminated only about 10,000 years ago. Modern polar and mountain glaciers represent the relicts of this glaciation. Beyond the polar regions the cooling was repeatedly interrupted by warming climatic trends; as a result, about eight "glacials" are distinguished. Recent data indicate that an older glacial period probably started near the end of the Pliocene, i.e. about 3 MY ago (the Deadman-Pass in California, U.S.A.), and it is suggested that this phase ushered in the Pleistocene Ice Age proper. Glaciation in the Antarctic probably started even earlier.

In addition to these Ice Ages there was one epoch of low temperature at the end of the Triassic (200 MY ago) when the evaporite belts became very narrow (fig. 1), and two

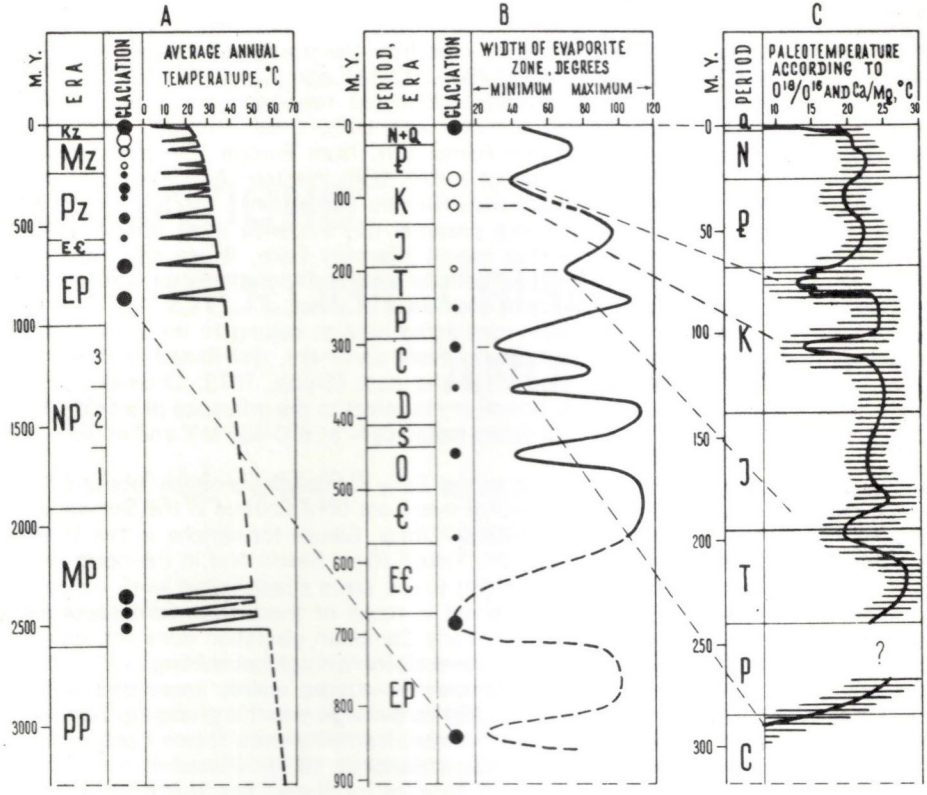

Fig. 1. Climatic changes and glaciations in the Earth's history. Precambrian stratigraphic scale after L. J. Salop (1973b), the "evaporite curve" after A. Meyerhoff (1970), the paleotemperature curve plotted by the author according to data of H. Lowenstam (1963), G. Stevens (1971). R. R. Teis and D. P. Naidin (1973), T. S. Berlin and A.V. Khabakov 1966) etc. Filled circles: glaciations, open circles: temperature minima.
A – The general trend in the change of average annual temperatures of the Earth's surface, glaciations and temperature minima during the Precambrian (Protozoic) and Phanerozoic. Era symbols of the Proto-zoic eon: Ep – Epiprotozoic, Mp – Mesoprotozoic, PP – Paleoprotozoic.
B – Curve demonstrating the maxima and minima in the evaporite accumulation during Late Precambrian and Phanerozoic times in accordance with the estimated evaporite zone extention along the latitudinal strike against the modern Pole of rotation
C – Schematic curve of sea-water temperatures in median latitudes during the Late Paleozoic and Mesozoic according to determinations of oxygen isotopes and Ca/Mg ratio in the shells of sea-animals.

during the Cretaceous – in the Aptian-Albian and in the Maastrichtian (115 and 75 MY ago). In the Maastrichtian the average global temperature fell to 10°C. These cooling trends are indicated by certain paleontological and geologic data, and numerous seawater paleotemperature determinations by Mg/Ca and oxygen-18/oxygen-16 ratios in animal shells (Lowenstam, 1968; Teis and Naidin, 1973, Meyerhoff, 1970; Stevens, 1971). The Cretaceous in general and its second half in particular is typified by widespread changes in seawater temperature and by a distinct climatic zonation.

I have argued earlier (Salop, 1973a, b) that the Precambrian glaciations occurred under very unfavourable physical-geographical conditions. The glacial deposits are interbedded between strata indicating a hot climate, such as red-beds, dolomites, phytolite-bearing

limestones (at present only forming in warm, usually mineralised waters along the seashore or in tropical lagoons and hot springs), evaporites, kaolinitic sandstones and bauxites. This association of tillites with formations of warm and hot climates is typical of the Paleozoic Ice Ages too. Clearly, an excessively warm and stable climate existed in the Precambrian and the Paleozoic. Faint relief and the existence of a dense carbon dioxide atmosphere favoured in the Early Precambrian a climate of hot-house azonal type, and in the Late Precambrian one of faintly zonal type (Salop, 1973b). Average temperatures at the end of the Precambrian were probably of the order of 35-40°C. Even in the Early Paleozoic climatic zonation was only faintly expressed and the average annual temperature was 30-32°C (Sinitsyn, 1967) (1). This supposition is substantiated by the continuous record of a heatloving flora in Devonian and Early Carboniferous strata at every latitude. Zonation in the floral distribution only becomes evident from the Middle Carboniferous onward.

The aperiodicity of glaciations. Many authors assume that an alleged periodicity of glaciations is related to the galactic year — the time of revolution of the Sun along the galactic orbit (Keller 1972; Lungershausen, 1975; Tamrasyan, 1959; Steiner and Grillmair 1973). However, the duration of the galactic year is not very well established; different authors attribute different values to it, mostly within the range of 190-275 MY, while recently many favour the highest value. According to Tamrasyan (1959), glacial epochs occur two times per galactic year, each time when the Solar System traverses the galactic plane, where abundant nebulae absorb the sunlight. With a suggested galactic year of 200 MY, glaciations should occur every 100 MY. Steiner and Grillmair (1973) contend that during the galactic year the Solar System moves (vibrates) three times perpendicular to the plane of the Milky Way, staying on one side for about 77 MY (Hatfield, 1970, suggests 60 to 80 MY). This periodicity would correspond to the glacial epochs, though in the geologic past the frequency could have been lower due to a postulated longer duration of the galactic year.

According to my data there exists no evident periodicity in the occurrence of major glaciations and temperature minima. In this case we can use data only from the Phanerozoic, for the periods separating the previous glaciations are not well established. The interval between the last Mesoprotozoic and the Early Epiprotozoic glaciation is approximately 1460 MY, but there are no data available on intermediate temperature minima which can be regarded as failed glaciations. Duration of the epoch separating the two Epiprotozoic glaciations is some 160-200 MY. The other intervals between glaciations or temperature minima are:

Pleistocene	) — 73 MY
Late Cretaceous	) — 40 MY
Early Cretaceous	) — 85 MY
Late Triassic	) — 50 MY
Late Permian	) — 45 MY
Late Carboniferous	) — 50 MY
Late Devonian	) — 95 MY
Late Ordovician	) — 125 MY
Early Cambrian	) — 110 MY
Last Epiproterozoic	

Thus, the intervals vary from 40 to 125 (or 180) MY and no evident periodicity can be observed.

1) Knaut and Epstein (1976) studied the isotopic ratios D/H and 0-18/0-16 in water of cherty rocks (silicium hydroxyl) and show that the average temperature of the Earth's surface was about 70°C during the Paleoprotozoic (3200 MY), about 52°C in the Late Precambrian and about 20°C at the end of the Paleozoic. At the beginning of the Triassic, however, the temperature increased again, up to 35°C, and then gradually fell to 15°C in the modern epoch. These data are consistent with my concepts on temperature changes during the non-glacial periods (see Fig. 1A)

The relation between Ice Ages and tectonic events

Some workers have suggested orogenesis as a cause of glaciation, but the lack of correlation does not warrant such a hypothesis. No Precambrian glaciation can be correlated with a major orogenesis (Salop, 1973b). The Phanerozoic glaciations and temperature minima exhibit a certain harmony with tectonic phases, but they cannot be closely correlated. The Phanerozoic tillites as a rule occur interbedded in sedimentary sequences, either far below or above the angular unconformities which denote tectonic events, and have gradual transitions into the wall-rocks. The Lower Cambrian tillites of South-West Africa are situated in the middle part of the Nama Group; they are much younger than the Katangian tectogenesis and much older than the Baikalian (Salair) one. The Upper Ordovician tillites occur in the Caradoc-Ashgill strata and thus were formed before the Taconian folding. The Upper Carboniferous Gondwana tillites were mainly formed between the Austrian and the Urals folding; only some of them seem to have accumulated at the end of the latter. The Upper Permian marine-glacial strata of New Zealand and the north-east of the USSR are situated within a thick and homogeneous sedimentary sequence. The temperature minimum at the end of the Triassic accords fairly well with the Early Kimmeridgian folding, but the next even more clearly expressed minimum of the Early Cretaceous was not associated with any tectonic phase. The Late Cretaceous temperature minimum falls between the Austrian and Laramide phases. And finally, the beginning of the Pleistocene Glaciation roughly coincides with the Valakhian (Caucasus) folding, but that seems to have no special importance. The Phanerozoic in general and the Meso-Cenozoic in particular are characterised by a higher frequency of tectonic events, and so a close relation of some Ice Ages or temperature minima with epochs of folding could be casual.

Thirty years ago Berg (1947) reached the same conclusion, and he emphasised that the cause of glaciations "is to be sought for among cosmic agents... The initial cause .. was the lowering of the air temperature and not the uplifting of some parts of the Earth's surface." (p. 324).

II. Biologic Crises and their Relation to Glaciations

Paleontological data indicate that the organic evolution of our planet is characterised by short-period mass extinctions and also by evolutionary explosions of large groups of animals and plants which must be regarded as revolutions in the history of Life. There is a definite time association of such biologic revolutions with the epochs of excessive climatic cooling usually resulting in glaciation.

The oldest known organic remains are from Paleoprotozoic strata (3500-2600 MY range) (2). These are the microscopic remains of blue-green algae and bacteria (procaryota) found in the Swaziland Supergroup and the Bulawayan Group of South Africa and in the Keewatin Group of Canada, and also some isolated occurrences of stromatolites from the carbonate rocks of the Bulawayan and Keewatin (Yellowknife) Groups. Further finds will undoubtedly be made but on the whole they are probably quite rare. The organic world at the beginning of the Protozoic lacked diversity and was of insignificant biomass.

An abrupt change in the fossil record, a true biologic explosion, occurred in the first part of the Mesoprotozoic, in the 2500-2300 MY range, as indicated by the appearance of thick horizons of stromatolitic dolomites and limestones in every sequence of this era on every continent; these horizons may be traced for tens and hundreds of kilometers (Salop, 1973). The stromatolite structures are characterised by a variety of forms. being built by

2) Many foreign colleagues attribute these strata to the Archean. In the scale here adopted, rocks older than 3500 MY are placed in the Archean; they are of high grade and form the Paleoprotozoic basement (Salop, 1973). Carbon-bearing rocks are recorded from that period, probably indicating the existence of older life forms.

many groups of blue-green algae and bacteria. Microphytolites are also associated with them, and the cherts enclose microscopic remains of procaryota, the simplest biologic group reproducing by cell-division. According to the Boston school of biochemists and microbiologists these organism are the ancestors of every life form now existing. This revolution was closely related in time to the Mesoprotozoic Ice Ages. The Lower Tillites of that era (the Government-Reef tillites in Africa, the Ramsay-Lake and Bruce tillites in Canada, the Sariolian tillites in Karelia) herald the appearance of stromatolitic dolomites; the Upper Tillites (the Griquatown tillites in Africa) rest directly on the stromatolitic bioherms. From the massive thriving of procaryota the outer shells of the planet were to experience great after-effects because of their photosynthetic activity. The appearance of free oxygen in the atmosphere (and hydrosphere) seems related to this event, and this in its turn led to the appearance and development of aerobic organisms; in the Late Mesoprotozoiç red-beds were formed, the first in the Earth's history (Salop, 1973) (Fig. 2). It resulted also in the disappearance of certain peculiar Paleoprotozoic or Early Mesoprotozoic formations.

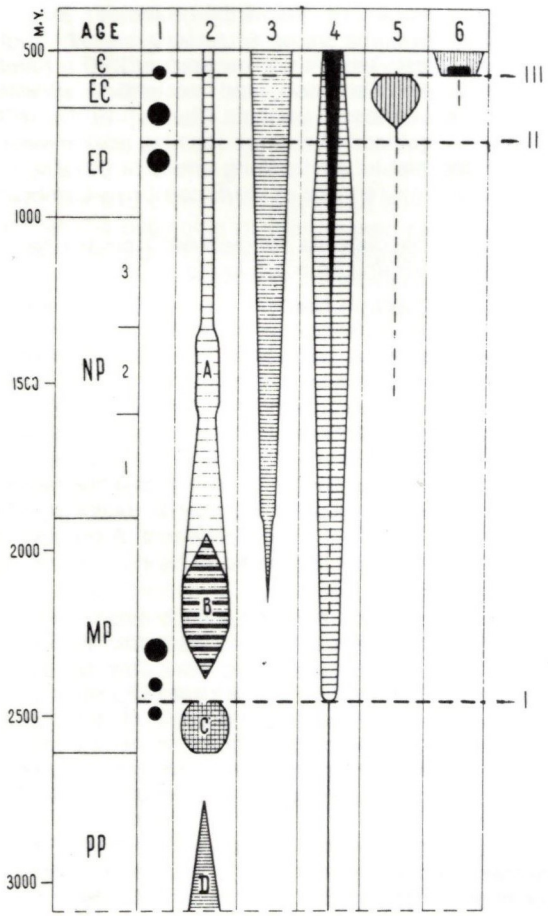

Fig. 2. Glaciations, oxysensitive formations and biologic revolutions in the Precambrian and Cambrian.
1 – glaciations; 2 – ore formations, showing a change in O-2 concentration in the atmosphere (A – hematite and siderite sheet ores of the "Urals type"; B – banded iron formation of the "Lake Superior" type; C – banded iron formation of the "Algoma type"; D – gold-uranium conglomerates); 3 – red-beds; 4 – phytolites (stromatolites and microphytolites), the filled inner contour – eucaryota; 5 – Ediacara fauna (the dashed line shows the presumed evolutionary "roots" of the first metazoans); 6 – skeletal fauna (the inner part of the contour in black: archaeocyatheans).

Biologic revolutions:

I – Mesoprotozoic: appearance and fast reproduction of blue-green algae and bacteria (the beginning of photosynthesis and the appearance of oxygen in the atmosphere);
II – Epiprotozoic: appearance of the Ediacara fauna of soft-bodied organisms (oxygen concentration in the atmosphere reached the "Pasteur point", 0.01 of the modern value);
III – Early Cambrian: appearance of skeletal fauna, appearance and extinction of archaeocyatheans.

The next biologic revolution of rank took place around the Epiprotozoic/Eocambrian boundary, in the 700-600 MY range. The soft-bodied Ediacara fauna acquired a wide distribution: principally coelenterates (in particular medusoids) and annelids, arthropods, and some problematic groups. The appearance of these first metazoa had occurred probably in the previous period, between the two Epiprotozoic glaciations, when the way to it was paved by a gradual increase in the oxygen content of atmosphere and hydrosphere favourable for the switch from a fermentative to an oxygenic type of breathing system, more advantageous in terms of energy consumption. Their massive expansion however can only be assigned to the Eocambrian period which followed after the last of the two glaciations (fig. 2). This fauna found no direct continuation in the Paleozoic, constituting probably an accessory evolutionary branch, though in the opinion of Pflug (1972) representatives of the petalonamae group are ancestral to a number of groups of skeletal animals of the Early Paleozoic.

The biologic outburst at the beginning of the Cambrian was exceptional. Various groups of skeletal animals appeared surprisingly quickly: trilobites, brachiopods, molluscs (gastropods and hyolites), sponges, echinoderms, archaeocyatheans and radiolarians. This fauna embraces thousands of species, with highly specialised forms and of unusual abundance. Both Eocambrian and Cambrian rocks are unaltered or they exhibit the same grade, and form single geohistorical or even lithological sequences. Below the boundary a skeletal fauna is lacking and representatives of the Ediacara fauna are as a rule very rare, although they occur up to the very boundary. In South-West Africa they are present in the Nama group, transitional between Eocambrian and Lower Cambrian, and are associated with crybrocyatheans and annelids typical of the lowermost Cambrian (Germs, 1974). It is noteworthy that many of the new forms, poorly equipped to tolerate the new environment, died out during the Cambrian. This biologic contrast is very striking and also puzzling. It must be underlined that this abrupt change in organic remains at the Eocambrian-Cambrian boundary is unique in the history of the Earth.

This revolution is also related to an Ice Age. Glacial deposits are recorded from the Nama Group among the strata that contain crybrocyatheans and Ediacara fauna.

In the Phanerozoic the most significant and abrupt changes in the organic world occurred at the ends of the Ordovician, Devonian, Carboniferous, Permian, Triassic and Cretaceous periods and also at the Pliocene-Pleistocene boundary. These changes have formed the basis for drawing boundaries between systems and series, and occur in various groups of fauna and flora almost simultaneously. In many cases rapid mass extinctions of large biogroups are recorded, after which a sudden proliferation of new forms belonging to the same group is observed. This is particularly evident in groups of lower taxonomic rank such as orders and families, to say nothing of genera and species. In every case the rapidly developing forms were more primitive or of limited distribution before the explosion and show an increase of their systematic variation and of their volume afterwards. A number of animal and plant groups also partly disappear suddenly at certain boundaries, followed by the sudden development of different groups.

The most striking biologic revolutions of the Phanerozoic are (in age succession):

At the end of the Ordovician several coral orders (tabulates) wholly disappear and at the beginning of the Silurian the first representatives of *Halysites* and *Favosites* started to develop. A number of trilobite families became extinct which in the Late Ordovician were thriving; the same happens to all graptolites of the leptograptine order, and to many brachiopod families. At the beginning of the Silurian the composition of the trilobite fauna became quite poor; the dimograpts appear, as do the first spiriferids and several pentamerid genera. Immediately after the sudden extinction of many groups, new forms typical of the Silurian start their rapid development.

In the Late Devonian the psilophytalean flora disappears completely. The Early Carboniferous flora evolved from the Late Devonian, but was characterised by wide distribution, variation and volume: forests of high-stemmed trees appear for the first time. Many grap-

tolites, trilobites, gigantostracans, ostracods, archaeogastropods, bryozoans, foraminifera, and a number of brachiopod families disappear, while new cryptogenic forms of ammonoids (*Clymenia*) and brachiopods suddenly appear, in particular the productids with some large-sized forms, and also the air-breathing molluscs. The first terrestrial tetrapods, the amphibians, which in the Late Devonian already existed, obtain a wide distribution. Abundant insects of the orthopteran group, some enormous in size, appear and expand most successfully (1000 species).

In the Late Carboniferous the cryptogenic glossopterian flora and other plant groups appear; the first indications of climatic zonation become apparent. Many brachiopods are reaching their end while new taxa of foraminifera acquire a wide distribution. In the Late Carboniferous and Early Permian the reptiles start their intensive development, reaching rather large sizes; ammonoids, ostracods and other groups also thrive.

At the end of the Permian the composition of the flora changed profoundly. The groups typical of the Carboniferous and Early Permian became extinct and were substituted by the gymnosperms characteristic of the Mesozoic: conifers and cycadophytes, and the gingcoaceous plants of which the first representatives had appeared in the beginning of the Permian. About 75% of amphibians and 80% of reptiles died out leaving no descendants (Newell, 1967). As to the sea animals, the last goniatites disappear as well as the last trilobites, tabulates and tetracorals, blastoids, ancient echinoids, many brachiopods (90% of the families including all productids and nearly all spiriferids), and among foraminifera the fusilinas and schwagerinas. At the same time, at the beginning of the Mesozoic, a rapid renewal of the fauna took place. Mammals appear for the first time, small in size; reptiles of the dinosaur group and the first sea reptiles came into existence. The composition of ammonoids, pelecypods, corals (hexacorals are registered), brachiopods and echinoderms (regular echinoderms are evolving) was subject to important changes.

At the end of the Triassic about 80% of the known families of reptiles became extinct and at the beginning of the Jurassic new groups started to develop very quickly, in particular the gigantic dinosaurs: therapods, sauropods and ornithichians; the pterosaurians appeared. The sea reptiles (plesiosaurs and ichthyosaurs), known since the Triassic as single representatives, reached in the Jurassic their acme; sea crocodiles and sea turtles also appeared. Even more important changes were observed among the ammonites: all existing families died out and in the Jurassic new cryptogenic representatives of this group, amounting to many families and species, started to thrive. Other cephalopods — the belemnites —, known since the Carboniferous, become widely distributed. Brachiopods are still in the process of extinction; during the Jurassic their ecological niches are occupied by pelecypods, mainly oysters. Great changes are also registered in the composition of corals, crinoids, and echinoids.

In the Late Cretaceous new revolutionary events are recorded. In the plant kingdom angiosperms developed rapidly and colonised the entire land area. The first representatives of this group are known at the beginning of the Cretaceous; during the Albian they started to develop intensely but a real biologic explosion is observed in the Late Cretaceous, when they become the dominant plant group. It is noteworthy that not a single group of the Mesozoic flora appears to be related to the angiosperms. Among vertebrates, the extinction of reptiles was most notable: about 60% of the families, including all large terrestrial and sea reptiles. Dinosaurs, pterosaurs, plesiosaurs, mosasaurs, and sea crocodiles died out. Toothed birds also became extinct. At the very start of the Cenozoic the fauna is utterly different. The mammals are dominant and start to evolve in many trends. Among the invertebrates the changes were as radical. All ammonites disappeared, and almost all belemnites which had been dominant among the sea fauna up to their sudden disappearance. Many families and genera among other invertebrate groups ceased to exist too. At the same time a sudden explosion of marine protozoans is observed, notably the coccolithophores and pelagic foraminifera which became rock-forming organisms. Some workers, e.g. Kuenen, regard this event as one of the important biologic revolutions.

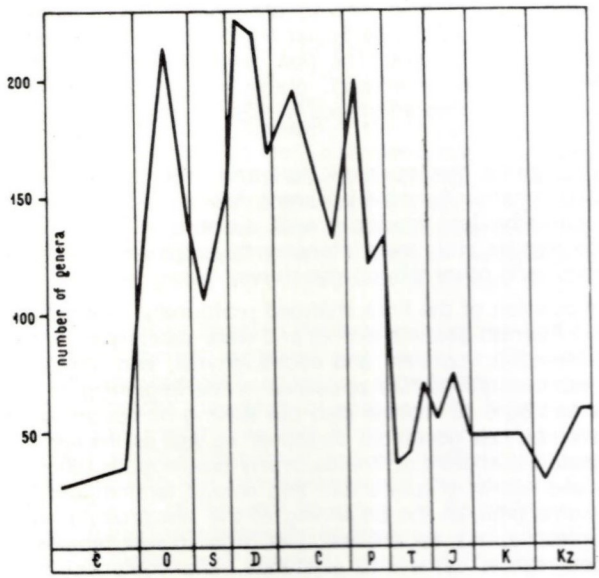

Fig. 3. Stratigraphic distribution of the number of genera of brachiopods (from "Treatise on invertebrate paleontology" – 1965).

At the end of the Pliocene, some 3 MY ago, is the last great revolutionary limit-line in the history of Life. The first ancestors of Man appeared and an essentially new epoch started, the Anthropogene or Psychozoic. All other changes in the organic world, however important, seem of minor significance in comparison with that event. The animal kingdom

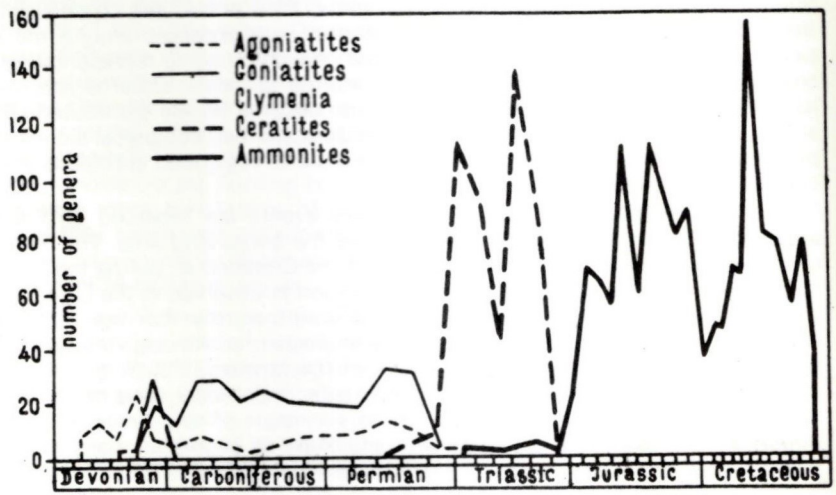

Fig. 4. Stratigraphic distribution of ammonoid orders according to the number of genera. The minor divisions of the stratigraphic scale represent the stages of each system. After V. I. Ruzhentsev (1957).

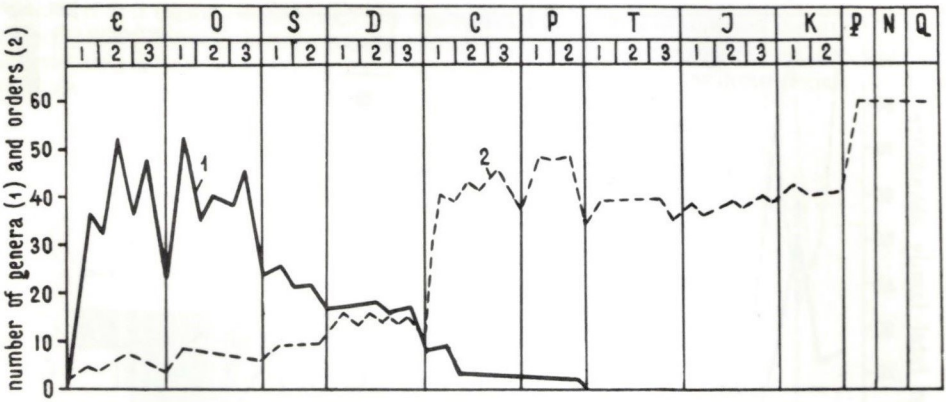

Fig. 5. Stratigraphic distribution of trilobites according to the number of genera (1) and of remaining arthropods according to the number of orders (2). After G. P. Leonov (1973)

of today originated, broadly speaking, also at that time, not counting the extinction of large animals in the second half of the Pleistocene thought to be largely caused by the activity of Man. Many forms of nannoplancton died out in the 3 – 2 MY time range (Gartner, 1973). Among plants of that period the grasses became widely distributed, the first representatives of which had appeared during the previous revolutionary epoch, the Late Cretaceous.

Figs. 3, 4, and 5 show changes in the abundance of genera and families of certain groups of invertebrates during the Phanerozoic. Abrupt changes are obvious at the above described limit-lines. These plots illustrate the regularities typical of many groups of invertebrates and vertebrates (Schindewolf, 1962).

Newell (1967) has analysed the abundance of families of the main animal groups during different geologic epochs, and plotted percentages of extinct families against the total abundance. According to his analysis, the major extinction of marine invertebrates fall at the end of the Cambrian (trilobites, archaeogastropods, sponges), the Ordovician (crinoids, brachiopods, corals, ammonoids, ostracods, archaeogastropods, bryozoans, foraminifera), the Triassic (brachiopods, ammonoids), and the Cretaceous (crinoids, ammonoids, echinoids, archaeogastropods, bivalves, sponges, bryozoans). The maxima of extinction among protozoans fall at the end of the Devonian, the Permian, the Triassic, and the Cretaceous.

Summing up the data on 2250 families, Newell compiled a diagram illustrating the maxima of first appearences and of extinctions among animals (Fig. 6), and concluded that 52% of all families died out at the end of the Cambrian, 30% in the Late Devonian, 50% in the Late Permian, 35% in the Late Triassic, and 26% in the Late Cretaceous. During these short periods between a quarter and one half of all animal families disappeared from the Earth, while the average rate of extinction during geologic epochs is about 17%, with a minimal rate of 3%. The extinctions are followed by a striking expansion in the newly opened ecological niches; the rate of evolution increased dramatically after these mass extinctions (Newell, 1967). Thus, what many earlier workers had established, was emphasised by Newell's quantitative analysis, and new details became available. It is also seen from his diagram that the principal revolutions in the Phanerozoic coincide in time with glaciations or temperature minima (Fig. 6), so that the regularities outlined for the Precambrian equally apply in the Phanerozoic.

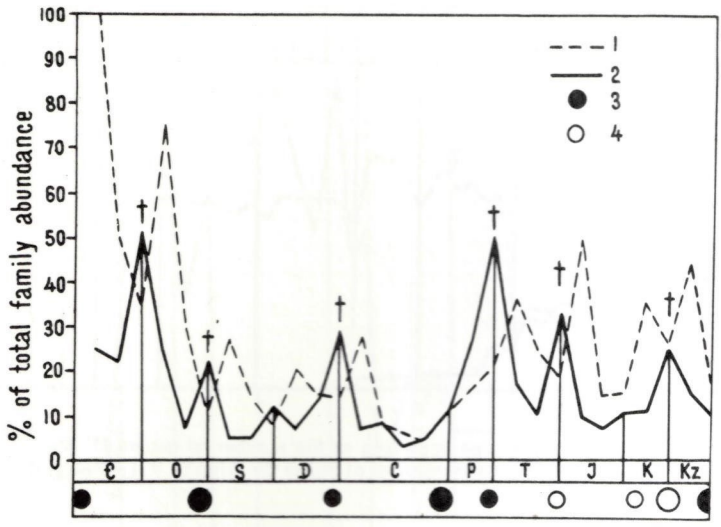

Fig. 6. Epochs of extintion and flourishing among animals (after N. Newell, 1967) with at the base of the figure additional data on epochs of glaciations and temperature minima. The plot shows the percentages of first and last appearances of animal families during geologic time:
1 – first recorded appearances; 2 – last recorded appearances; 3 – glaciations; 4 – temperature minima.

III. Possible Causes of the Crises

Glaciations correlate in time with biologic crises and so we might be tempted to conclude that the latter were caused by the first. Lichkov (1945) has suggested that mass extinctions are caused by a deficiency in food related to a low supply of fertile elements (ash and organic remains) to the soil, during the xerophilisation of climate that commonly follows Ice Ages; this perturbation in ecologic equilibrium would be detrimental to some forms and favourable for others. It seems farfetched, however, to invoke such perturbations as causes of the biologic crises; they are not necessarily of a global scale and could at most influence the development of a few species or groups. Recent biological and ecological studies show that the role of the environment, sensu stricto, has been grossly overestimated and that biologic evolution is mostly related to genetic factors.

If a cause-and-effect relationship between glaciations and biologic crises is inferred we would be making a well-known logical error: *post hoc, ergo propter hoc*. The crises are characterised not only by mass extinction but also by the sudden expansion of new groups, and a lowering of temperature or its secondary effects cannot account for both phenomena, and even less for the Precambrian revolutions expressed only by the sudden development of many forms and not by extinctions. Furthermore, the global scale of glaciations is suggested only for the Precambrian, not for the Phanerozoic when a warm and even hot climate prevailed over extensive regions permitting the heatloving organisms to migrate and survive. Not every organism is susceptible to temperature changes and many animals can stand large temperature fluctuations. Even the more sensitive animals such as

amphibians and reptiles, which lack thermoregulation, somehow survived climatic changes (Colbert, 1968). Several biologic groups, living in different environments and with different reactions to change of temperature, such as the reptiles and the ammonoids, show a parallel development (see fig. 7).

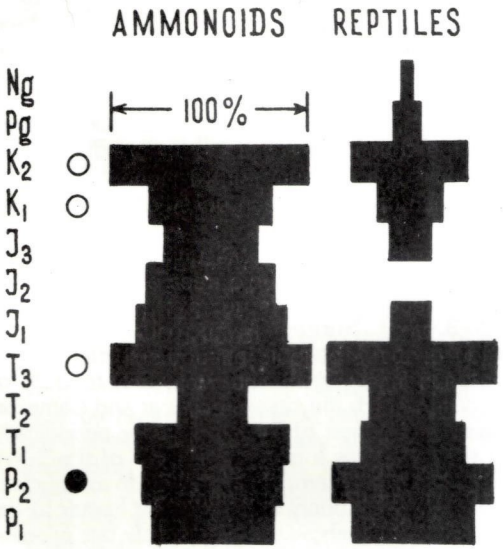

Fig. 7. Parallel extinction of the ammonoid and reptile families (after N. Newell, 1967) with additional symbols: the filled circles-glaciations, the open circles-temperature minima. The diagram shows the percentage of the extinct families.

Undoubtedly, many different causes may have contributed to the crises, such as changes in sea salinity, in paleogeographic conditions, wider distribution of carnivores, severe epidemics, etc. However, that developments occurred simultaneously in many groups suggests the existence of a single major cause, and the time correlation with glaciations forces us to reject all hypotheses which do not account for both phenomena. For instance, changes in the obliquity of the ecliptic or volcanic eruptions accompanied by large outbursts of pyroclastic material produce a change in insolation but have no mutagenic effect, and there is no close time correlation between Ice Ages and known periods of maximal volcanic activity. Moreover, the average temperature of a given geological period is reestablished soon after an Ice Age: we can hardly assume a rapid return of the ecliptic to its point of departure.

During a temporary increase of solar activity accompanied by the formation of sunspots and magnetic storms, the ultraviolet (UV) radiation increases sharply. This radiation is very sensitive to slight temperature increases in the Sun's chromosphere; an increase of only 88° causes a double intensity of UV radiation. This results in the formation of ozone in the upper parts of the atmosphere and the creation of a heat shield through the effect of CO^2 and water vapour, producing the hot-house effect.

Eigenson (1963) demonstrated that the formation of the ozone shield causes an intensification of cyclonic activity and of climatic contrasts ("the law of accentuation"). In the humid regions of higher latitudes this could result in glaciation. Thus, a general rise of temperature can provoke a local glaciation, paradoxical as it may sound. The effect would be of short duration and of little consequence.

The solar rays emitted during chromospheric flashes are relatively powerful but their average contribution to cosmic radiation is only a few percent. Moreover, these rays present a much softer energy spectrum than the galactic radiation and are thus of lower penetrative capacity and mutagenic action. If such flashes thus could contribute to initiate a glaciation, they can hardly be regarded as responsible for the biologic crises.

As argued earlier (Salop, 1973), it is impossible to explain the glaciations of the Precambrian, when a hot azonal climate prevailed, by a terrestrial agent. The cause must be looked for in some cosmic phenomenon, most probably a change in intensity of the solar heat reaching the Earth's surface. During the Phanerozoic, average temperatures decreased significantly, and terrestrial agents would also be able to provoke global climatic cooling, or else a combination of terrestrial and cosmic causes could have been active.

The simplest cause of a temperature decrease seems to be a variation of the solar energy emission. The measured variation in value of the solar constant does not exceed 2 or 3%, evidently not sufficient to account for a sharp decrease of overall temperature of the Earth. Many astrophysicists thus suggest that the Sun is a stationary star with a relatively stable thermal regime. However, because of the great deficiency of solar neutrinos reported by R. Davis, some workers return to the conception of the Sun as a variable star (while others favour different explanations and do not acknowledge a variable Sun). According to Fawler (1972) the high temperatures needed to start nuclear reactions are achieved in the inner parts of a star only at certain times, every 200-300 MY. Subsequently, due to convectional instability, the heated matter moves upward mixing with less heated surface matter; in this case the insolation goes down for some 35% and the temperature on the Earth for 30% or more. This process would last about ten million years. In the opinion of Ezer and Cameron (see Shklovsky, 1974a) an abnormal increase of emission of nuclear energy periodically happens in the interior part of the Sun and this produces a quick expansion of the Sun's core, followed by a lowering of its temperature and a temporary cessation of nuclear processes. Both ideas are in agreement on the intensive supply of energy and matter to the surface of the Sun when the stability of its interior is somehow upset; possibly this process is accompanied by an increase of hard radiation.

These hypotheses may help explain the Earth's glaciations and biologic explosions. However, certain contradictions between the hypotheses and the geologic data are to be noted. First, these ideas advocate a periodicity in the process of mixing (or expansion) of the Sun's interior, which the available data on glaciations and biologic crises do not reveal. Second, the postulated extreme variations of temperature are contradicted by the paleontological evidence of biologic continuity.

The Supernova Hypothesis. Many workers studying the abrupt changes in various biologic groups in the geologic past were unable to find explanations other than radiation. Thus, Ivanova (1955) came to the conclusion that an abrupt change in groups of soft-bodied marine organisms of the Middle and Late Carboniferous of the Russian Platform is not related to any change in the physical-geographical environment but can only be explained by some global cause, which she suggested to be a change in radioactivity level at the Earth's surface. The suggestion that biologic crises are somehow influenced by radiation produced during flashes of Supernovae was first advocated by Schindewolf (1950) on a general scale; he developed the details in subsequent publications (Schindewolf 1954, 1958, 1962). Krasovsky and Shklovsky (1957), and Shklovsky (1974) independently formulated the same concept, suggesting that acceleration in mutation rate is caused by intensive radiation of relativistic particles from Supernova explosions in the vicinity of the Solar System. I have suggested (Salop, 1964) that the biologic explosion at the beginning of the Cambrian was due to accelerated mutagenesis under the effect of cosmic radiation from Supernovae.

These concepts were at first vigorously disputed but in the past ten years they have been regarded more sympathetically as new findings in radiation genetics have been divulged.

Cosmic radiation is now accepted by many workers as a possible cause of biologic revolutions, especially of the mass extinction at the end of the Cretaceous (Bernal 1967; Hatfield 1970; Terry and Tucker 1968). It is to be stressed, however, that the advocates of the "cosmic hypothesis" explain by mutagenic radiation not only extinction but also sudden expansion.

Only radiative mutagenesis can influence organisms in many directions at the same time. This hypothesis can also explain other features, such as: the sudden appearance of many new groups of organisms, and simultaneous explosive reproduction leading to a great increase of biomass; sudden proliferation of groups which evolved previously at a slow pace (commonly such groups appeared first during the former revolution); rapid extinction of biologic groups soon after their expansion; the appearance of gigantic forms of animals and plants, and the orthogenetic development of certain organs; parallel development and extinction of different groups (for instance the ammonoids and the reptiles, cf. fig. 7).

The succession of glacial and interglacial epochs during Great Glaciations could also be explained by the passage of the Solar System through condensed or rarified parts of the galactic nebulae characterised by an irregular distribution of gas-and-dust particles, magnetic fields and ionising radiation (3). As to the Pleistocene glacial period, the solar hypothesis of Milankovich may satisfactorily explain the succession of glacials and interglacials, or they may be due to the heterogeneity of the nebulae.

Thus, the most probable cause of glaciation seems to be the shielding of the solar heat flow by huge gas-and-dust nebulae formed during flashes of Supernovae. Such nebulae are numerous in our Galaxy and present the remains of stars exploded long ago. While expanding with a velocity reaching 1000km/sec, they exist for scores of thousands of years. If a Supernova explodes somewhere in the vicinity of the Solar System, the Earth would be shielded from the Sun and remain subject to cosmic radiation for a long period. There does exist a certain proportionality between the time periods of the events and of the statistically determined frequency of the explosion of Supernovae in the vicinity of the Solar System. Some astrophysicists argue that the incidence of cosmic rays on the Earth's surface is now abnormally high (Shklovsky, 1974b), just as many share the opinion that the modern climate is abnormal and related to the end of the glacial period. (Nairn, 1963; Fairbridge, 1966).

Today, there is no unanymous support for the "cosmic hypothesis". As before, some workers doubt it or even denounce it as a mystic concept. Such an accusation however is by no means justified, as will be shown below.

IV. Recent Research Data.

Hard radiation. Hard radiation consists of ultra-violet (UV) and ionising radiation. The major part of solar UV radiation is stopped in the upper layers of the atmosphere by the ozone shield, formed by dissociation of water molecules under the effect of UV and cosmic radiation. However, UV radiation increases greatly with an increase of solar activity. Growth of the solar constant by only one percent results in an insignificant rise of temperature of the troposphere, but the UV radiation multiplies 100,000 times. This increase causes a corresponding intensification of the ozone shield and so the hard radiation at the Earth's

3) The nebulae formed during Supernova explosions have very intensive magnetic fields which surely would affect the magnetic field of the Earth. Could they not be responsible for the observed complex pattern of the residual geomagnetism? This becomes especially emphasized if the spotty-filamentary structure of magnetic fields is taken into consideration. In this case paleomagnetic studies could not be applied in the reconstructions of plate tectonics.

surface does not become much higher (4) It cannot be ruled out, however, that in the geologic past UV radiation has been more important, for the ozone shield was very weak then.

Ionising radiation can come from Supernovae or from the Sun. The remnants of Supernovae emit the most powerful flow of cosmic particles, with energies of the order of some thousands of GeV to 10^{12} GeV and even more. Solar activity in comparison produces much smaller flows of particles with a much softer energy spectrum, commonly a fraction of 1 GeV, and only in rare powerful flashes of the chromosphere reaching 100 GeV.

The cosmic rays of lower energy are also shielded by the atmosphere, and the magnetic field of the Earth diverts the charged particles, trapping part of them in the radiative belt at about 1000 km from the planet's surface. Thus, only the hardest radiation penetrates the atmosphere, and the intensity at the Earth's surface is a function of the geomagnetic coordinates; in the polar regions the geomagnetic barrier is totally lacking.

The cosmic rays of higher energy interact with the nuclei of nitrogen and oxygen atoms in the Earth's atmosphere and as a result unstable particles are formed: π-meson and some others. The charged π-meson is transformed into μ-meson which is capable of penetrating the atmosphere and even soils and rock to a depth of some 20 m, though its energy is moderate, about 10 GeV. The μ-meson of higher energy penetrates still deeper, down to 8600 m it the oceans.

The so-called Supernovae, mighty bursts of stars, are rather frequent. Several were observed in our Galaxy during recorded history, at a rate of approximately one per century. For example, the well-known Crab nebula is due to a Supernova exploded in 1054 A.D. However, high radiation on Earth is only generated by Supernovae in the neighbourhood of the Solar System. Shklovsky (1974) thinks that these occurred several times during the history of the Earth. Terry and Tucker (1968) estimated from observations of the remains of these bursts that Supernovae generating a radiation dose of 500 roentgens (R), lethal for many animals on the Earth's surface, explodes every 50 MY; those creating a dose of 1500 R, every 300 MY, and a dose of 25,000 R, every 600 MY. For these evaluations the influence of the interstellar magnetic fields was neglected. Lester (1968) has shown that the expected radiation intensity would be much less if the effects of these fields were taken into consideration. During geologic time there have been no bursts of 25,000 R close to the Solar System, otherwise Life on Earth would have been annihilated. The fossil record attests that Life was evolving and diversifying during the entire history of the Earth (the "law of biologic continuity"). Also, the particles do not move in a straight line because of the magnetic fields, but they meander, and in spite of their velocity commensurable with that of light, it will take them much longer to reach the Earth. Thus, while radiation originating from near Supernovae reaches the Earth in a relatively short time (years or decades), radiation from distant sources can take thousands of years or more, and would produce only weak radiation during a longer period.

Biologic Effects of Hard radiation. Different animals possess different sensitivities to radiation. In a general way, "in the hierarchy of living animals the radioresistivity decreases with an increase of the quantity of genetically important structures which do not have common functions. On the other hand the functional duplication of genetic material results in an increase of radioresistivity within the associated organisms (diploid organisms are more endurable than haploids) (Shevchencko and Shilenko, 1969, p. 344).

A dose lethal during 30 days after the radiation is from 250 to 600 R for mammals (500-1000 for man) and 8000 to 20,000 R for reptiles. Single-celled organisms are far more resistent, the lethal dose being 30,000 R for yeast, 10,000 R for amoebas, and 300,000 R for infusoria (Dubinin, 1969). The lethal dose for various groups of plants spans a very wide

4) See below for possible meteorological effects of an increase in UV radiation.

range. Grass is more durable than forest trees. A short-term radiation of 20,000-40,000 R, ruinous for every plant but for some primitive algae, spores and seeds, does not produce any evident damage on grass. Woodwell (1963) gives the following data: pines are killed at 20-30 R per day during six months or at 1000-2000 R during a day; for deciduous trees these doses are 30-60 R and 5,000-10,000 R respectively, whereas for grasses they are 100-300 R and 20,000-40,000 R. Moss and lichen persisted at a momentary dose of 200,000 R. The blue-green algae are the least sensitive to radiation, being capable of living under conditions similar to those in a nuclear reactor. The seeds and spores of plants are also very resistant. The lethal dose for the seeds of agricultural plants embraces a range of 10,000 to 50,000 R. Pine seeds keep their vital capability after a dose of 12,000 R during one day. Thus, plants will be killed off by a short dose of very high radiation but can be reproduced by their seeds.

Short-term intensive radiation and long-term low radiation do not as a rule produce the same biologic effect. Unfortunately, very few data are available on the long-term effects, which are of special interest for the geologic past. Many biologists (e.g. Woodwell, 1963), however, suggest that a very long radiation of low dosage could have serious implications in biology due to the accumulation of damage in the genes of successive generations. The biologic effects of ionising radiation do not become apparent at once. It depends not only on intensity and duration of the radiation and on the radioresistivity of the organism, but also on its "genetic load", duration of vital cycle, rate of reproduction and number of populations. Two kinds of processes take place after exposure: those removing the radiation damage and those aggravating it.

The primary and secondary effects of radiation are also to be distinguished. The direct effect happens only during exposure, which can be very short, almost instantaneous. The radiation, however, leads to the formation of radioactive isotopes in the atmosphere and on the Earth's surface, and the duration of their biologic influence is determined by their decay constant. For instance, after the atmospheric nuclear explosions between 1945 and 1963, the concentration of the dangerous isotope C-14 increased twice in the atmosphere. As its half-life is about 5600 years, its effects will last for 11,000 years and influence 300 generations of people (Dubinin, 1969).

Water provides protection against strong UV and ionising radiation. A dose of 1000 R at the surface of the sea will at a depth of 25 m be lowered to 72 R and a dose of 5000 R at a depth of 50 m to 116 R. Certain components of cosmic emission (μ^- mesons, for instance) can penetrate, as stated above, down to a great depth. The secondary effect of the ionizing radiation can also be registered because the accumulation of radioactive isotopes acompanies the accumulation of sediments. In modern sediments cosmogenic Be-10 is reported at a depth of 5000 m. Various organisms inhabiting the surface waters (algae and planctonic animals in particular) form the food components of deep-water fauna and thus the ecological relations between plankton and benthos make the protective action of the "water shield" far less powerful.

Radiation genetics. Biologic change may occur in two ways. Physical and chemical agents can effect the embryo, in which case the modification is not inherited and thus of no importance to evolution. Inherited changes take place in the chromosomes, by recombination of genes in crossing and in mutation in particular. Mutation can be of two types: the "spontaneous" mutations caused probably mainly by the constant background radiation, and others caused by problematic factors of which hard radiation is one of the most important (5). Spontaneous mutations are rare (one mutation per 200,000 or even per

5) Mutations called forth by chemical reactions are of far less importance for biologic evolution. They cannot account for episodic biologic revolutions as there are no grounds to assume sudden and very short-term global changes in the chemical environment.

1000,000 genes) and cannot be responsible for important changes; on the contrary, they are likely to provide stability to the living system. Hard radiation however increases the mutation rate many times and quite abruptly.

Mutagenesis by radiation is not directed, and the genetic variations are hap-hazard, they are registered statistically in large populations. Most mutations are unfavourable for the organism, which lacks vitality or even dies, owing to defects in metabolism or secretion, or to hormonal and other insufficiencies. Certain mutations end in orthogenesis, i.e. the excessive development of a few characteristics, adversely affecting the very life of organisms and initiating their extinction. The mutations commonly cause greater damage in the more complex organisms, for their genetic aparatus is more vulnerable then are for instance protozoa. The latter, in addition to plants, have greater chance to be favourably affected by mutation. Radiative mutagenesis can result in both higher and lower rates, and the final result depends on the number of populations and their rate of reproduction. The modifying effect of mutation and selection can be strong and also last for a long time.

The evolutionary selection as advocated by Charles Darwin is accompanied by selection for viability at the molecular level. Schevchenko and Shilenko (1969) state that "low radiation background, without any selective action, does not provide motive energy for evolution; high radiation creates, on the contrary, an unconquerable barrier for multifold selection for radioresistivity, and results in degradation of a population. An optimal level of background radiation is supposed to exist for evolution to continue developing radioresistivity." (p.345-346).

So, according to modern genetic science, there is no evolution without mutation, and mutagenic hard radiation becomes indispensable for evolution.

Conclusions.

It is difficult to evaluate the possible effects of radiation on extinct organisms; many aspects of their biological functions are unknown and experiments concerning their radioresistivity cannot be carried out. We only can apply the concept of actualism, extrapolating to older forms the results of experiments on modern organisms.

Many scientists — Oparin, Bernal and Calvin amongst others —, on the basis of experiments by S. Miller, suggest that hard radiation was necessary for the emergence of life ("biologic systems") from organic compounds of non-biologic origin (Bernal, 1967). So the first and most important biologic revolution, the appearance of Life on Earth at the beginning of the Archean era, would be related to cosmic radiation.

The next biologic revolution, in the first part of the Mesoprotozoic, characterised by the rapid expansion of blue-green algae and bacteria, is proposed here to be the result of cosmic radiation affecting the simple phytoplancton which existed then. It is interesting to note that very soon after the nuclear explosions on islands in the Pacific Ocean, blue-green algae reestabished themselves in the lagoons and on the seashore. They immediately occupied all vacant ecological niches and for a certain period were the only life forms there. Their rate of reproduction was surprisingly high. We may assume that cosmic emissions of the past also stimulated cell-division, and promoted the formation of nucleus structures in the cells and the appearance of the first single-celled eucaryota algae with alternation of asexual and sexual generations. The absence of competitors also favoured their expansion.

During the Epiprotozoic revolution the first animals appeared, the soft-bodied Ediacara fauna. Presumably, cosmic radiation could provoke their appearance (or evolution) and also their later extinction, at the beginning of the Cambrian.

The cause of the biologic revolution at the beginning of the Cambrian, when various and complicated cryptogenic skeletal groups came into existence, is very puzzling. Many ready-witted hypotheses have been advanced but none of them provides a satisfactory explanation. The puzzling nature of this "biologic explosion" lies not only in the simultaneous appearance of many skeletal organisms but also in their high organisation and speciali-

sation. Berkner and Marshall (1965) developed the concept of the effect of a higher concentration of atmospheric oxygen on the appearance and evolution of metazoans. Great attention should be given to this idea, but it does not explain the suddenness of the biologic explosion. The cosmic radiation hypothesis seems to account better for the known facts, but somehow it is not quite conclusive either. The few forms of the Ediacara fauna which give indications of an outer skeleton died out together with the whole fauna at the end of the Eocambrian. Conceivably some primitive forms, soft-bodied or with a faintly developed skeleton, appeared in the Eocambrian and were ancestral to the Cambrian fauna. It is of interest that clear creeping tracks of trilobites are reported from the lowermost Lower Cambrian and even from probably Eocambrian strata situated stratigraphically far below the rocks bearing the first trilobite skeletons. Crybrocyatheans, the peculiar organisms with a cup-shaped outer skeleton and resembling archaeocyatheans, appear in the Precambrian-Cambrian boundary beds much earlier than the true archaeocyatheans typical of the Lower Cambrian. An intensive cosmic radiation at the beginning of the Cambrian thus could have killed the Ediacara fauna and on the other hand produced viable mutants which evolved fantastically rapidly forming the various groups of Cambrian animals.

Loeblich and Tappan (1964) contend that the mass extinction of planctonic microorganisms (mainly foraminifera) at the end of the Permian was due to cosmic radiation which especially could affect protozoan evolution. Mayers and Worsley (1973) studied the calcareous nannofossils of the Upper Maastrichtian in Alabama, concluding that the fossil populations attest radiation variations, which they postulate to be related to a change in solar activity. The mass extinctions followed by a sudden proliferation of foraminifera at the end of the Devonian, the Carboniferous and the Cretaceous could also be explained by cosmic mutagenesis.

The bones of dinosaurs and uintatheres, extinct at the end of the Cretaceous, reveal a radioactivity exceeding several times that of fossils of other periods. In Central Asia and elsewhere several large occurrences of bones of Late Cretaceous dinosaurs are reported which proved to be radioactive with a high concentration of uranium (Jaworowski and Pensko, 1967). This concentration might be of secondary origin, due to the adsorption of uranium by the bone tissue, but even so the uranium could find its origin within the large bone occurrences which originally could have been enriched in this element (and also in Sr, Ba, Zr, Tr and Th). Probably nucleosynthesis of heavy elements occurred during the explosion of Supernovae, an assumption according well with modern ideas of cosmochemistry (Sobotovich, 1971).

The most important evidence of cosmogenic mutagenesis as a cause of extinction was obtained in studies of eggs of the Late Cretaceous dinosaurs. These eggs possess a very thick shell consisting of several layers, as in pathological cases among modern poultry. This phenomenon, called *ovum in ovo,* is produced when the mature egg is not laid but returns, sometimes repeatedly, from the excretory canal back to the oviduct; in every return a new shell is formed. This many-layered shell results in the death of the embryo for the pores supplying oxygen for breathing become stopped up. Such pathological development was reported in nine species of fossil reptiles found in Provence. The only possible cause of this phenomenon seems to be a mutation provoking hormonal defects (Kirillov, 1970).

The cosmic mutagenesis hypothesis can also be applied to the revolutions in the development of various plant groups. The rapid spreading of the angiosperm flora during the Aptian-Albian and in particular at the end of the Cretaceous is regarded as "the greatest puzzle" by some scientists. Golenkin (1974) suggested "a sudden and consequenly, cosmogenic reason": solar radiation would have increased strongly and under its effects the plants would have formed new stable types resistent to higher brightness of light, lower air humidity and extreme changes in temperature. An intensive burst of radiation, pernicious for the conifer forests, could have been below the danger-threshold for leaf plants, which thus would have received a break in their evolution.

The sudden seizure of territory by herbaceous plants (including cereals) together with the disappearance of many groups of conifers and leaf plants at the Pliocene-Pleistocene boundary also seems to be accounted for by radiative mutagenesis, for the grasses display an exceptional radioresistivity. The appearance of the ancestors of Man during this revolution was conceivably also due to radiation provoking a quickening in the evolution of the anthropoids. Even now mankind might be exposed to the long-term effects of distant ionising cosmic radiation; Shklovsky (1974b, p.77) affirms that "the now existing density of cosmic rays near the Earth is abnormally high, not typical of the "average" periods of the evolution of life."

It is no exaggeration to state that the entire Life on Earth is intimately related to cosmic emissions, which penetrate every organism and every cell. The well-known biologist Chizhevsky has demonstrated the interrelation of many biologic phenomena and the variations in solar activity. Lovelius and Maximov (Maximov, 1972) found that during Supernova flashes recorded in human history (Tycho Brahe's star in 1572, Kepler's star in 1684, and Cassiopeia-A in 1700) the year rings of thousand-year-old trees of the Turkestan archa reveal a sharp lowering of growth rate lasting for some 15 years, suggesting slight radiative damage to the tree cells.

The Earth, together with the Life it supports, is not a closed self-developing system but constitutes an integral part of the Cosmos. Solar rays together with galactic and cosmic rays are life-giving; it is impossible to imagine the appearance of Life or its evolution without the effect of these rays. Our environment, sensu lato, embraces the whole Universe.

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GALACTIC DOMAINS, G FLUCTUATIONS AND GEOMAGNETIC REVERSALS

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Summary

The degree of constancy of the universal constant of gravitation G is discussed. The hypothesis is presented that a constant G is subjected to occasional short-duration fluctuations at times of reversal of the geomagnetic field. Evidence suggests a correlation between field reversals and deformations of the Earth's crust, and the hypothesis is further supported by the one to four frequency correlation between the galactic cycle and related sedimentation sequences.

1. The Constancy of G

The universal constancy of fundamental physical constants over a cosmic time-scale is a basic issue in theoretical physics. The theme owes its primary appeal to a proposal by Dirac (1937), who constructed, from the fundamental atomic and cosmological constants, certain dimensionless ratios, which had the numerical value of approximately 10^{39}. From this empirical basis Dirac argued that all such very large dimensionless constants are in reality changing parameters characteristic of the present state of the cosmos. In particular the ratio e^2/GMm was deemed to increase in proportion to the age of the universe. The electron charge e, the proton mass M, and the electron mass m were taken to be truly constant, with the constant of gravitation G decreasing with time.

The idea has been a stimulus to theoretical physics but is thwarted by experimental evidence which strengthens the case for true constancy of all the basic quantities involved, including Planck's constant h, the fine structure constant α, the speed of light c and even the Hubble constant H. Wolfe, Brown and Roberts (1976) show that quasar observations demonstrate a variation of α by less than 4 parts in 10^{12} per year and less than 2 parts in 10^{14} per year for g (m/M), where g is the gyromagnetic ratio of the proton. Recent dimensional analysis by Landsberg and Bishop (1975) reveals an intriguing link between the order of magnitude of elementary particle mass (10^{-25} gm) and the parameters h, c, G and H. If this quantitative link is given its due weight then the assumptions used in the analysis mean that this mass quantity and e, h, c and H/G are all time-invariant.

The key issue then is whether G is truly constant or, as Dirac's theory suggests, whether

it decreases with time, the same condition applying to H. Unfortunately, paleontological evidence suggests that G remains constant.

Evidence for G remaining constant has been reviewed by Swetman (1972) and includes reference to radar-echo experiments between planets Earth and Mercury from which it is argued that G cannot vary more than by 4 parts in 10^{10} per year. This particular evidence does not avoid the possibility that the basic hypothesis is valid, inasmuch as a decrease of G by a few parts in 10^{10} per year is nevertheless a variation. Towe (1975) argues, however, that geological evidence posed by the study of crystal structure in rocks is strongly opposed to any noticeable variation of G over the past 3.10^{9} years. This result is inferred from the fact that there is no evidence of the concomitant matter creation process within Precambrian crystals. G is constant on this basis and Dirac's hypothesis stands refuted.

The proposal that G is time-invariant over the cosmic time-scale stands in sharp contrast with a whole series of cosmological theories summarized by Wesson (1973). Wesson relates these to the hypothesis of the expanding Earth, a phenomenon which must be intimately linked to any decreasing variation of G. It is, therefore, interesting to pose the question whether G can change in a way which would defy detection by the experimental techniques just mentioned.

2. The Space-Domain Hypothesis

In view of the intimate links between space and time, the above question leads us to ask whether G is constant only in the sense that there is a very strong probability that at any instant it has the same value. It may be subject to occasional fluctuation within the earth system in dependence upon the position of the Earth in the space-time continuum. Are there perhaps discrete domains in space within which G is universally the same but which have boundaries affecting the Earth's gravitation in its transit from one space domain to an adjacent domain? Let us consider the hypothesis that G is a universal constant subject occasionally to local transient change as the system affected moves across a space-domain boundary. Note that, in discussing whether astronomy needs new physics, Ginzberg (1975) has speculated that a homogeneous stable vacuum may be characterized by a quantity $\sigma = 1$ applicable to domains within which σ may differ in sign. These domains are separated by domain walls within which σ changes continuously from $\sigma = 1$ to $\sigma = -1$. Ginzberg had gravitational field quantization in mind and was contemplating very small domains but we could stretch our minds in the other direction and ask whether domains having dimensions measured in light years are feasible as well.

This argument can be advanced in the following way. Suppose that G can be linked in a unified field theory to electrodynamic interactions and that the parameter σ in the Ginzberg scheme is electrical in character. We may then expect the domain boundary transits to be marked by two phenomena, a transient fluctuation of G and a reversal of polarity of space-dependent electrical effects. The latter would be a reversal lasting until the Earth, for example, encountered the next domain boundary in its path, whereas the former would be of a few seconds duration.

The new physics providing a domain structure in space would introduce a preferred reference frame, possibly relevant as a base frame for cosmic background radiation. This then would give an indication of the speed of the Earth relative to the domain system. Concklin (1969) has shown that our planet moves at about 160 km/s relative to cosmic background radiation. The Earth has a diameter of 12,750 km and so would traverse a domain boundary in 80 seconds for a normal interception. An oblique crossing would mean that it would sit astride two domains for a rather longer period. A weakening of G between the Earth's matter for such a period would have a violent effect upon the crust. Earth rotation combined with the relaxation of the gravitational force would accentuate the surface non-uniformities and cause an east-west shift of the crustal substance. There would possibly be some expansion followed by slow settling over the years before the next

space domain was encountered. Yet, having regard to ecological effect, life forms must, in the main, survive the violence of these few seconds.

This is speculation, but no more speculation than that involved in the large number hypothesis discussed above. The space domain hypothesis links two phenomena, the catastrophic upheavals accompanying domain boundary crossings and the simultaneous polarity reversals of electrical character.

3. Geomagnetic Reversal Evidence

Is there evidence that crustal upheaval and reversal of an electrical or magnetic nature occur together in the Earth on a recurrent basis in geological history? The answer is affirmative because the geomagnetic field reverses polarity from time to time. Note that a reversal every 10^6 years taken with the speed of 160 km/s implies a space domain size of the order of 500 light years.

The proposal in this paper is, therefore, that the cosmologies depending upon variable G should include one for which G is a universal time-invariant constant, subject to G being zero for action between matter straddling both sides of a domain boundary. The development of such a cosmology has purpose only if there is geological evidence of an association between geomagnetic field reversals and crustal deformation. A preliminary glance at the research literature is encouraging, as outlined below. First, however, it is to be noted that geomagnetic field reversals do not occur at regular intervals, as we see from the book 'Continental Drift' by Tarling and Tarling (1971). The last five million years show a sequence of irregular reversals, usually occurring in pairs with occasional intervening single reversals.

This suggests that the Earth is moving through a cubic-structured space domain system. Bear in mind that movement in the 100 direction implies a long interval between reversals, movement in the 110 direction close to a corner of a cubic domain implies two reversals in rapid succession, and movement in the 111 direction close to such a corner could give three reversals in rapid succession. Movement at an angle oblique to all three domain axes which, in our era, carries the Earth half way between the 110 orientation and the 111 orientation and passes near domain corners only in respect of its 110 component, would give a sequence of pairs of reversals with intervening single reversals.

Looking for evidence of a related violent activity when the field reverses we see in Tarling and Tarling (1971) the comment:

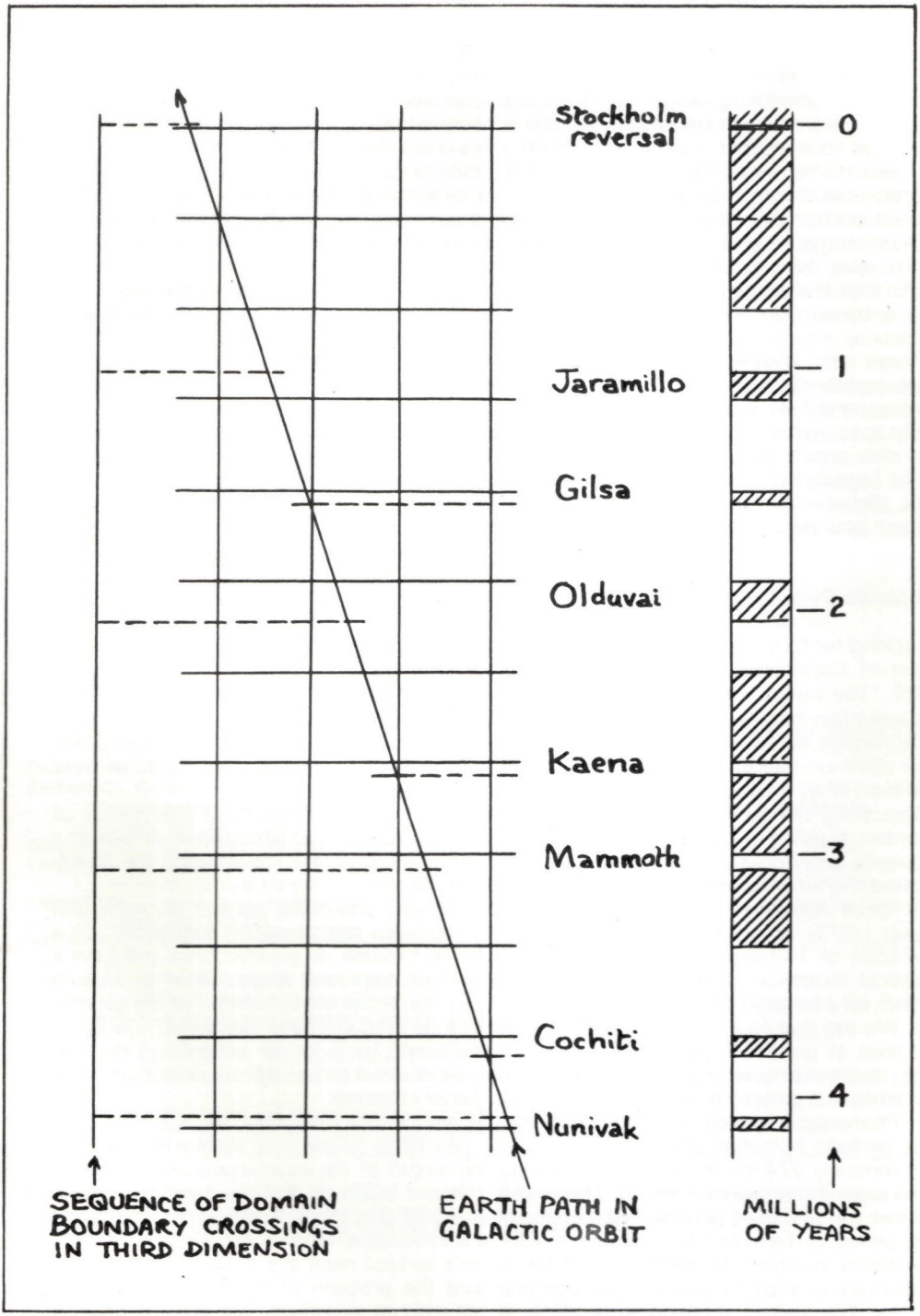
'One of the fascinating side lights of the study of these sedimentary cores is that many fossil species were found to disappear about the time of a reversal and new species appeared shortly afterwards.'

The magnetic field reversal of itself is hardly likely to explain such an event.

According to the Tarling data the last geomagnetic field reversal was about 700,000 years ago. A study of the deep-sea floor of the Indian Ocean is reported to reveal tiny metallic and glass beads which, it was said (Wright, 1972):

'..... were fragments of some great cosmic catastrophe that caused molten particles to splash into the atmosphere some 700,000 years ago. The shower of debris coincided with the last reversal of the earth's magnetic field.'

As the Earth crosses a domain boundary in space along with the whole Solar System, the Sun would also experience the weakening of G for about two minutes, possibly accounting for activity causing such a cosmic event. The perturbations due to fluctuating gravitational action between the Sun and planets will be inappreciable in the cumulative sense over the cosmic time-scale, but observable disturbance of the planetary orbits would be in evidence at such times. The 'shifting of heavenly bodies' on which Velikovsky (1950) dwells in discussing the reports of Plato in the context of the story of Atlantis and the great catastrophe 9000 years before Solon (11,600 years ago), may be merely fantasy, but recently, it was reported (Emiliani et al, 1975) that analysis of deep-sea cores from the Mexican



Pattern of geomagnetic field reversals due to motion through cubic domain space during past 4 million years.

Gulf pointed to a late-glacial surge possibly some 11,600 years ago. This is claimed to be evidence for the Flood, since it is in full agreement with Plato's date. Now, although this may not be a relevant catastrophe in the scheme of domain space outlined above, it is important to note that a lapse of 700,000 years since the last geomagnetic field reversal suggests that a reversal and the consequent upheaval must be about due. The Tarling data indicate that during the past 700,000 years the direction of the geomagnetic field has remained unchanged. However, since the Tarling book was published (1971) a discovery in Sweden suggests that there was a reversal about 12,400 years ago. Morner and Lanser (1971) who, with Hospers, were responsible for the Stockholm discovery, also reported (1975) that there was a 90° excursion of the magnetic declination some 12,350 years ago. This is based upon test specimens taken from the southern part of the North Atlantic Ocean.

These data, coupled with the hypothesis presented in this paper, suggest that the Earth went rapidly through two domain boundaries at about that time. The reversal of the geomagnetic field would be retarded by eddy-currents in the Earth's core and these could easily account for a time constant measured in hundreds of years. Thus the two reversals may only appear as a transient in the geomagnetic field. Whether this event could be linked to the later-dated Flood is a matter for speculation. However, giving weight to the geomagnetic disturbance reported, it seems improbable that the Earth can encounter another domain boundary for another 500,000 years or so.

4. Galactic Cycle Evidence

Looking for further data, we take note of a contention by Wegener in his classic work 'The Origin of Continents and Oceans' which dates from 1915. Quoting from a recent text (1966): 'The forces which displace continents are the same as those which produce great fold-mountain ranges. Continental drift, faults and compressions, earthquakes, volcanism, transgression cycles and polar wanderings are undoubtedly connected on a grand scale. Their common intensification in certain periods of the Earth's history shows this to be true. However, what is cause and what effect, only the future will unveil.'

Discussing the theory of these cyclical events, Steers (1964) speaks of one theory of mountain building involving sima passing through successive solid and molten phases at a frequency between 33 million years and 60 million years, but casts doubt upon the theory because the mountain-building has not been so regular.

Of more relevance to the space domain hypothesis presented above, we note that Steiner (1973) reports a possible galactic relation between sedimentation sequences. On a time scale of 10^8 years we can expect the Earth to traverse its galactic orbit and have a statistical incidence of domain encounters of varying approach angle. Draw a circle at random on a squared pattern, the radius being, say, ten times the dimension of the squared grid. We see that four times per revolution the circular orbit will have intersections with the grid lines at grazing angles. This means G disturbance for a longer period and that the Earth, in describing an orbit in space, could have a statistical probability of greater upheaval four times in a galactic period. Note then that Steiner observes:

'If Phanerozoic geological history incorporates any periodicities, they are of the order of 60 or perhaps 70 million years..... The galactic periodicity of the solar system is, however, approximately 274 millon years, representing the length of the cosmic year, or one revolution around the galactic centre.' This is very relevant evidence, but the question remains whether the proposed periodic fluctuations of G would give the right answers taken over a long period of time and fully accounting for the successive random crossings of domain boundaries in which different parts of the Earth's surface meet the boundaries first. The momentary change of gravitational potential and the problem of energy balance needs analysis. The idea of G changing suddenly is not easy to assimilate, but if the geological evidence helps then the basic physics involved is worth rescrutiny.

Gravitational potential is merely a measure of the intrinsic ability of the field medium to release energy as mass elements move into closer proximity. Energy thereby freed may have become thermal energy in matter and dispersed throughout space. If the fundamental action regulating this energy transfer relaxes momentarily it does not mean that the resulting potential has instantly to be balanced by a flow of energy back to the field, to be released again when the action reverts to normal. Gravitational force could therefore undergo a transient relaxation without the gravitational potential presenting any special difficulty. In a cosmological model favoured by the author the large-scale release of gravitational energy when astronomical bodies are created develops spin in the field medium which may eventually be shared by the body. Such field spin accounts for the main magnetic field. Given such a buffer action of a spin system, which is slow to exchange energy with matter, it is easier to understand why the gravitational energy exchange is not a reversible adiabatic process.

On the cosmic scale the idea has more to offer, especially when one considers what might happen to a large star which finds itself travelling through a space domain boundary when moving nearly parallel with the boundary. A critical reduction in the effect of G for a short but long-enough period could well result in some stellar manifestation. Whatever be the outcome of such speculation, our Earth provides us with enough food for thought and, until we are satisfied that there is a viable explanation for geomagnetic field reversals and the possibly-related geological periodicities, we must be open to the thought that space itself has structure interacting with our Earth.

I wish to record my thanks to K.M. Towe of the Smithsonian Institution in Washington for his kindness in drawing my attention to the above-referenced work of Steiner.

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  Glass from the impact rim around the Lake has been radiometrically dated at 1.3 to 1.6 million years, a period when Africa was inhabited by Australopithecines.

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After a banquet in ancient Greece, guests received some eatable or drinkable gifts, APOPHORETA - 'things to be carried off', to take home. On this page a column is published in which provocative hypotheses are presented. They may serve to stimulate thought and research - and the correspondence for the 'Comments' column of this journal.

APOPHORETA - 4 - ΑΠΟΦΟΡΗΤΑ

To explain the discontinuous nature of the fossil record - which is characterised not only by sudden massive disappearances but even more by sudden massive appearances, occasional bursts of radiation have been proposed independently by several students of Earth history (Schindewolf, 1950; Velikovsky, 1955; Salop, this issue).

Anomalous high radioactivity has been detected in Homosteus, a fish from the same Old Red Sandstone beds in which the Pterichthyodes occur, fishes often invoked by catastrophists of different persuasions (Hugh Miller, George McCready Price, Immanuel Velikovsky) as bearing witness to a sudden, violent and massive burial. Hugh Miller wrote, in 1841:

"The River Bullhead, when attacked by an enemy, or immediately as it feels the hook in its jaws, erects its two spines at nearly right angles with the plates of the head, as if to render itself as difficult of being swallowed as possible. The attitude is one of danger and alarm; and it is a curious fact (..) that in this attitude nine tenth of the Pterichthes of the Lower Old Red Sandstone are to be found (..).

"At this period of our history, some terrible catastrophe involved in sudden destruction the Fish of an area at least a hundred miles from boundary to boundary, perhaps much more. The same platform in Orkney as at Cromarty is strewed thick with remains, which exhibit unequivocally the marks of violent death. The figures are contorted, contracted, curved, the tail in many instances is bent round to the head; the spines stick out; the fins are spread to the full, as in Fish that die in convulsions (..). The record is one of destruction at once widely spread and total, so far as it extended (..). By what quiet but potent agency of destruction were the innumerable existences of an area perhaps ten thousand square miles in extent annihilated at once, and yet the medium in which they had lived left undisturbed in its operations?"

Latter-day uniformitarians tend to explain the radioactive anomalies by differential adsorption of radioactive elements posterior to deposition. Conceivably this will bear out to be correct, but it could be only a partial explanation. Has any study been undertaken to find out whether high radioactivity in fossil bones correlates with the great faunal breaks of the Earth's history?

Han Kloosterman

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in forthcoming issues:

René Thom on catastrophe theory and plate tectonics

Pietro Passerini on knowledge and entropy

George Choubert on the transmutation of elements and granite genesis

Albert V.Carozzi on the effect of tornadoes on carbonate rocks

Johan B.Kloosterman on the Tunguska explosion and the concept of actualism

Eugène Wegmann on a glacierlake spill in Greenland

Haroun Tazieff on the formation of guyots

Roger G.Cooper on William Buckland and the Duncombe Park fissure

also forthcoming:

A special issue on THE COMING GEOCHEMISTRY